APPLICATION OF COMPUTER MODELING AND SIMULATION TECHNIQUES FOR OPTIMIZATION OF FACTORY FLOOR OPERATIONS IN SMALL TO MEDIUM-SIZED BUSINESSES

Brian P. Romano

D. Abbott Turner College of Business and Computer Science

The Graduate Program in Applied Computer Science

Application of Computer Modeling and Simulation Techniques for Optimization of Factory Floor Operations in Small to Medium-Sized Businesses

A Thesis in

Applied Computer Science

By

Brian P Romano

Submitted in Partial Fulfillment
Of the Requirements
For the Degree of

Master of Science

December 2014

I have submitted this thesis in partial fulfillment of the requirements for the degree of Master of Science

June 17, 2016

Date | Brian P. Romano

We approve the thesis of Brian P. Romano as presented here.

June 24, 2016

Date | Shamim Khan, Professor of Computer Science, Thesis Advisor

Jun 24, 2016

Date | Radhouane Chouchane, Associate Professor of Computer Science

Jun 15, 2016

Date | Hoda Mehrpouyan, Assistant Professor of Computer Science

June 24, 2016

Date | Wayne Summers, Chair of TSYS School of Computer Science

ABSTRACT

The rationale and motive for this thesis was to prove that no matter the size of a company and its particular value stream, the application of applied computer science principles with a reliance on computer modeling and simulation onto the factory floor process improves efficiencies and throughput through the reduction of downtime and/or process waiting. This thesis research specifically emphasized small businesses of between $2 and $20 million and was purposely limited to factory floor production processes and utilized standardized applied computer science techniques including simulation and modeling, microprocessor based factory floor intelligence devices. The results of this applied technology yields data driven decisions through established production management programs such as Six Sigma and Lean techniques. The resulting research shows that methodologies developed here can be used in market segments that can't now afford to implement these efficiency programs and as such, the application of the proposals brought forth in this thesis should precipitate an increase in US Small Business manufacturing efficiencies.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

Availability One of the three OEE components. Availability takes into account any Downtime events (these are events that stop planned production for more than a minor/negligible amount of time).

Cycle Time The time required for the machine to produce one piece.

Downtime Analysis Tool used to better understand issues that affect Availability. Typically easiest completed using Pareto analysis.

Downtime Production time lost to unplanned shutdowns.

Theoretical/Ideal Cycle Time Theoretical minimum time to produce one part.

Theoretical/Ideal Run Rate Theoretical maximum possible production rate (1 / Ideal Cycle Time).

OEE (Overall Equipment Effectiveness) Calculation for measuring the efficiency and effectiveness of a machine and/or process accomplished by determining the three OEE components.

OEE Components The three individual elements that figure into the calculation of OEE (Availability, Performance and Quality).

Operating Time Production time remaining after Downtime is subtracted.

Performance One of the three OEE components. Performance takes into account losses that cause the process to operate at less than the maximum possible speed when running.

Planned Production Time Total time that the machine/process is scheduled for production operation.

Planned Shut Down Time purposefully scheduled with no production planned.

Plant Operating Time The time the equipment is available for operation.

Quality One of the three OEE components which take into account parts that do not meet quality requirements and are considered scrap or rejects.

Six Big Losses Six categories of productivity loss typical in manufacturing: Breakdowns, Setup/Adjustments, Small Stops, Reduced Speed, Startup Rejects, and Production Rejects.

Small Stop A brief stop in production that is not long enough to be considered as downtime event. One of the Six Big Losses.

ACKNOWLEDGMENTS

This point in my life is coming well after I thought it would and the way that I arrived here is a story all of its own but simply put, since my graduation from high school in 1981 has been a long, circuitous route, but I relish what I have done and all the experiences and knowledge gained along the way.

I need to approach this area chronologically as to try to not miss anyone. First, my Mom and Dad. They both gave me the good lot of genetic “fodder” as well as a wealth of experience, advice and most of all, a plethora of love and support. Mom, you say that my “smarts” couldn’t have come from you, but believe me, it does. Thank you! Dad, I wish you were here to see this. I think of you often and can’t help but know that you were a key influence to me.

Next come all my teachers, especially the ones that coaxed me out of my shy shell as a kid. There are two teachers in high school that standout in particular that I give credit for my success. Ms. Eleanor Woike, my teacher for three out of four years bringing me through Geometry through Calculus while imparting knowledge to me that still lasts with me today. Mr. Frank Besancon, who I had for 6 classes in four years (4 years of electronics and 2 years of Physics) as well as a couple of study halls, gave me my start and was most certainly the reason for what and who I am today. Between his selection of me as being one of the few of his electronics students working for a summer as an electronics technician, to his mentoring and guiding words all combined helped to shape my

future. Mr. B passed away in the mid 80's doing what he believed most in; arguing in front of a Board of Education lobbying for a technology program in the school system he had moved to after leaving my hometown. The world lost a great man and educator as well as an influential person on that day. Thank you Ms. Woike and Mr. B (Skippy).

After graduating high school and after getting my AS degree and after a couple of balked attempts at finishing my BS degree, being a bit of a competitive personality, I finally committed to finishing my BS degree, vowing to get mine before my oldest daughter got hers. I enrolled in a college and a program that I knew was going to be more difficult than I was used to and I knew my reintroduction to academia was going to be a bit of shock. But luck was with me when I drew this one teacher – Noah Baerman – whose positive attitude and teaching demeanor gave me a great feeling of confidence during which I started feeling that "I could do this" and his class put me on a roll. Thank you Noah!

As I come to the close of my MS in Applied Computer Science there are a bunch of "Thank you" and acknowledgements that need to be made. Dr. Wayne Summers, who made it an easy decision to attend CSU and who has always been there with a supporting statement and answer…Thank you!

I would also like to extend a hearty thank you to my instructors while at CSU and also would especially like to thank the professors involved in my thesis project. With that, I would like to thank Dr. Charles Turnitsa and Dr. Radhouane

Chouchane for taking their extra time to help me in this endeavor. A special Thank You with extreme gratitude to Dr. Shamim Khan for his patience and guidance in what had become a lengthy endeavor.

Taking in all, there are many mentioned here and a great deal more that are not. Please be sure, you are not forgotten or not appreciated. With my whole heart, "***Thank You***" to all the influences, family, friends, teachers and mentors in my life. It certainly has been special!

DEDICATION

This dedication has a few facets. I dedicate this to my children who have kept me young hearted and involved and who were all my “study buddies” and my role-models of stick-to-it-ness during my years of my return to college and without their support I know I wouldn’t have been able to do this. My thirst for knowledge and learning was rekindled through all four of my children. Thank you Heather, Alyssa, Christina and Adam.

To my wife April….what can I say? I am dedicating this to you because of all the years of dedication you have shown me. Your support, kind words and especially your inspiring words to keep me on track at the low and difficult points all these years are probably the most important reasons I was able to complete all these challenges and tasks. I love you and especially thank you for being mine and getting me to this awesome point in my life. Your turn!

Case Study Plan

STATEMENT OF PROBLEM

Having spent more than thirty years in the industrial automation market, there are distinct levels of ability to invest in capital equipment with high tech control equipment. That level of investment goes hand in hand with the ability to make the most of the investment by leveraging the control equipment into a secondary mode of data collection.

This level of higher tech control equipment pays back dividends where certain shortcomings, inefficiencies and overall process data can be collected allowing for either offline, or even online, data analysis. That data can be as good as gold as it reveals the story of the factory floor and large companies are aware of this fact and leverage the data capable controllers on their machines to involve themselves in quality initiative programs such as Lean/Six Sigma.

So in lies the ability of companies with large enough capital budgets to take advantage and leverage the inherent control equipment. Being a small business owner as well and having firsthand experience in what it takes for a company of less than $20 million in sales, the general need is to make use of what it has and be creative and ingenious in using what it can and where it can.

Having been involved in companies in all sizes, as mentioned in the abstract, there is a disparity between the level and complexity of production equipment and that

disparity seems to exist in companies sized between $2 million and $20 million in sales. These companies, in the opinion of this author, are the backbone of the US economy as they far outweigh the larger companies in sheer quantity and continue to utilize production equipment from the 1950's through the 1980's that contain virtually no level of intelligence and are either based on cam driven motion or that utilize rudimentary sensors to control the machine operation. These companies make up 82% of the US economy (U.S. Census Bureau, 2012) and if given the chance that a great majority had the ability to improve throughput and efficiencies, the outcome would yield very large results.

With the existence of the quality initiative programs such as Lean/Six Sigma, companies armed with the proper plant floor production metrics can plug the data in the tried and proven techniques and algorithms which allows for production of tale-telling graphics and data driven decision making. The discrepancy with this is that experience has shown that companies that have revenues in excess of $20 million buy "higher end" equipment and machinery which will typically have computer/CPU based control equipment on it that also contains the ability to be networked and have data metrics pulled from it. Experience has also shown that companies with gross revenues of less than $20 million tend to buy legacy or "non-intelligent" production equipment as they are more cost effective because the production capability to capitol dollar ratio is lower. However, production statics for companies having annual revenues of approximately $2 million to $20 million per year can certainly be improved if able to employ data programs such as Lean / Six Sigma.

To that end, without a minimum of automation or intelligence in the production control systems there is no practical way that a company can participate in any of the well-known continuous improvement programs such as lean/six sigma. It is this dilemma that this thesis study is based upon and for which the following research questions will be studied and answered:

After identifying companies that fit the revenue and technology constraints, through the use of modeling and simulation and other inexpensive applied computer science technologies, can overall equipment effectiveness and other related efficiencies be elevated to a level comparable to companies able to purchase machinery containing high technology control and SCADA systems?

PURPOSE OF STUDY

In an effort to emulate programs prevalent in larger companies, while also attempting to allow smaller companies to participate in programs that can pave the path to better efficiencies and productivity, the purpose of the study was…to prove that the application of applied computer science principles based first in computer modeling and simulation improved machine efficiencies and throughput through the reduction of downtime and/or process waiting. The applied methodology utilized a custom designed, standalone piece of industrial data gathering equipment by connecting it to the legacy production equipment having little to no automation intelligence. Using this computer-based modeling and simulation and other distinct methodologies implemented in this study, it is shown that these small companies with less intelligent, legacy equipment can be included in machine efficiency and effectiveness programs.

Long established programs such as Lean, Six Sigma and the combination program, Lean/Six Sigma, have the tenets of DMAIC (Mike George, 2004, pp. 56 - 77):

Define the subject for improvement

Measure the process

Analyze the process data

Improve the process based on the results of the analysis

Control and sustain the improvement

From these tenets, it can readily be seen that without a means to measure and analyze the process data the ability to improve the process would not be possible. It is with this, that this study gives the small business owner, the organizations with legacy and less expensive equipment, a plan and a tool to perform the M and A portions of the process.

PLAN METHODOLOGY

The outline of the plan for the study of the two sample machines was considered to follow these general steps:

- Identify and qualify that the company revenue is between $2 million to $20 million in annual revenue. In addition, assure that even though the company falls into the proper revenue size, the company, and especially, the machine, does not participate in an automated data gathering program and gather production statistics.
- Interview machine operator for production statistics, both theoretical/design and actual.
- Develop a model and run a simulation of the machine/process using off-the-shelf simulation software (Rockwell Automation ® Arena) to validate the production statistics received during the interview process agrees within a reasonable figure (+/- 10%). The 10% figure was chosen so as to allow some variability due to inaccuracies in the information received by the operators.
- Install a data gathering box developed specifically for this study onto the machine/process and production and downtime statistics are gathered for a nominal period of time. For this study, the preliminary period is one to two weeks.

- Examine the data from the box and put it into two formats; the downtime by reason is put into a Pareto chart to easily identify the main reason(s) for the machine being offline and the process data consisting of machine cycles, uptime and downtime (and good parts and reject parts, if available) is trended and filtered to check for inconsistencies or trends that would yield further evidence of the inefficient operation of the machine/process.
- Make recommendation(s) based on the analysis of the data. A recommendation to the operation of the machine/process is made and the original model changed to reflect the recommendation. The model is then run for simulation to verify the intention of the change in operation.
- Implement the change on the actual machine and the data gathering box is reset and run for a nominal period of time to gather the data, comparable to the initial study time frame, keeping the results based on the same time frame.
- Compare the data from the machine to the changed model and simulation to validate the results.

Due to the length of time required for the last two steps stated above, they will be completed post thesis and the corresponding data are not included in this text. It will however be collected for possible future publication.

Appendix 2 contains a brochure that was designed to explain the above plan to the proposed companies for study.

As described above, the main issue of the inability of small manufacturers to implement Lean/Six Sigma or other similar types of efficiency programs is the lack of inherent technology to extract data from the plant floor equipment. When a small business procures a piece of used or rebuilt equipment for substantially less than that of new, the sacrifice made here is that the machine will more than likely be several generations back in technology in terms of control systems. While the production need of the machine – to manufacture parts for the customer – is satisfied, the rudimentary construction of this asset but does not allow the manufacturer to easily implement any type of tracking of machine data.

To that end, the main premise of this study was to add that missing level of tracking with a somewhat simplistic electronic metric device. This device can be deployed using one of two manners: a custom embedded CPU board level device that was specifically programmed for the function; or, to use a built-up system comprised of off-the-shelf components that can be quickly and readily constructed, programmed and deployed. Considering these off-the-shelf devices are directly meant for industrial environments, are robust in nature and are programmed using standardized graphical Boolean logic languages, direct use of these devices for the purposes meant for this thesis study were directly aligned.

Below in Figure 1, two such boxes are shown. Figure 2 below indicates that the display on the front contains a touch screen to be used for input by the operator.

Figure 1 – Data Gathering Control Systems

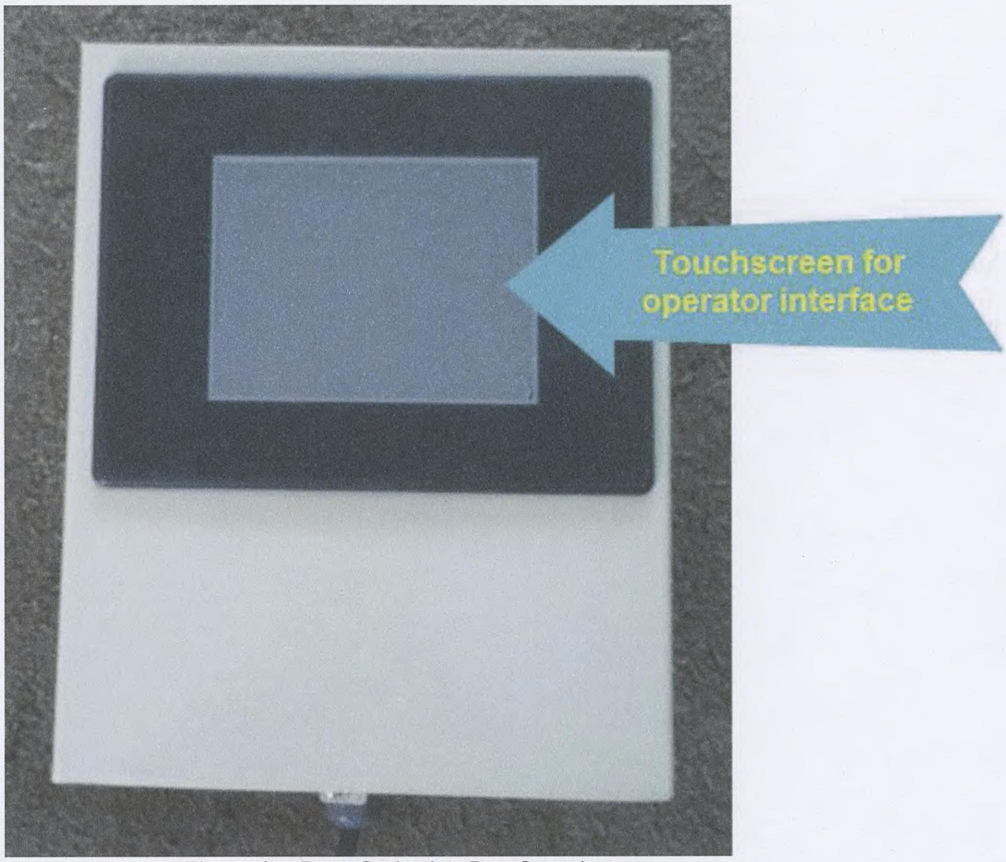


Figure 2 – Data Gathering Box Overview

Figure 3 below breaks out the particular hardware contained in the system. The system components have been mounted and the contents arranged to be able to accommodate the interface wiring done to the system. Within the photo, as shown by the respective blue arrows, terminal strips are available for DC inputs, DC outputs and AC outputs. Also contained in this is a small isolated relay (shown in the top right corner of the photo). This relay is somewhat critical in the ability to get accurate data from the machine for without it there is no insurance that the data collection system could be used. Without the inclusion of this relay forcing the hand of the operator, the resulting collected data would be either skewed or completely inaccurate.

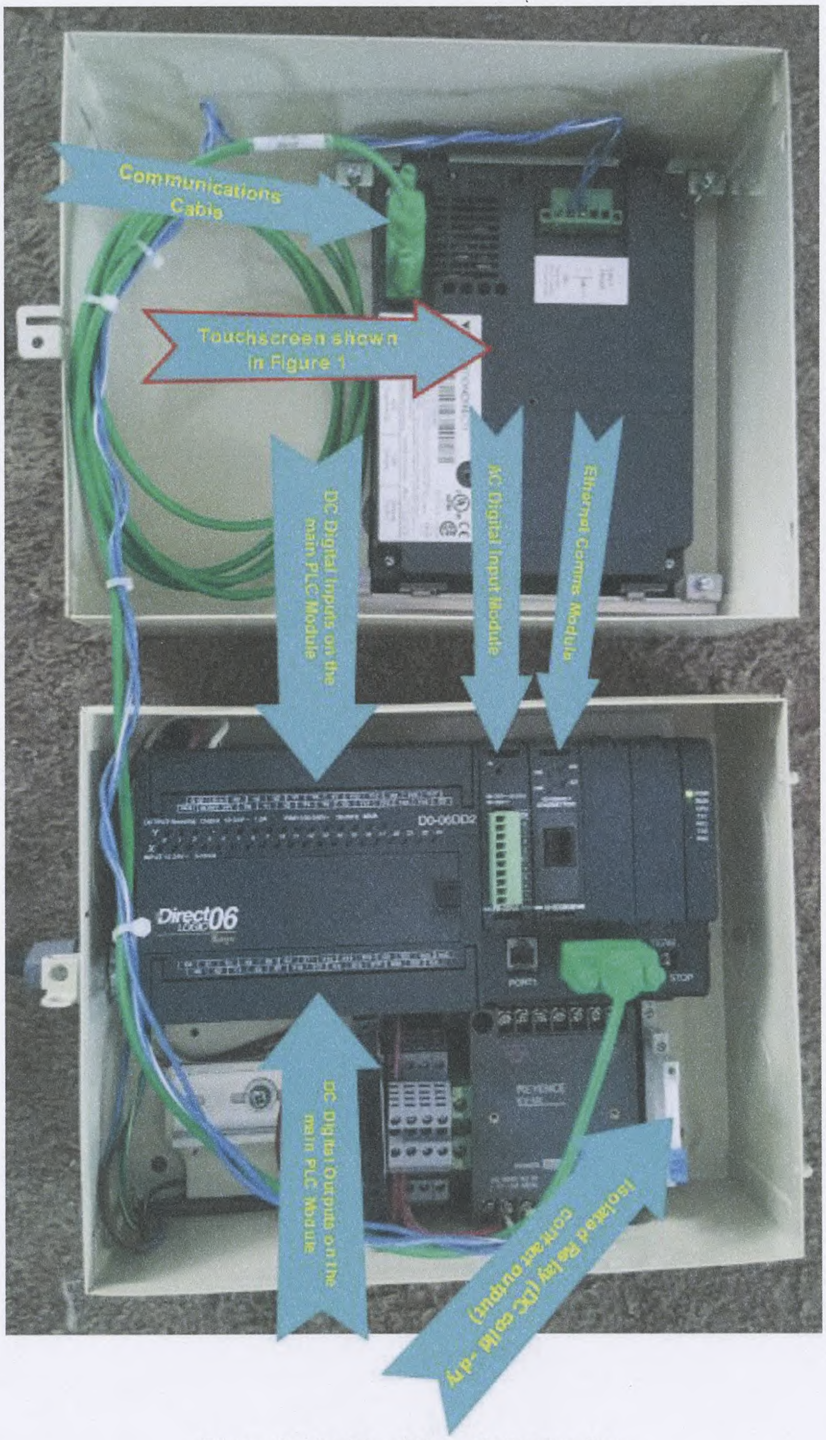


Figure 3 – Inside of Data Gathering Box

The above system was mounted near the machine of interest and a maximum of three input sensors used to sense the machine production points. It was proposed to sense the following:

- Machine cycle – an input was sensed for every one machine production iteration
- Good part sensing – if an inspection and built-in quality system is present, this sensor registers every occurrence that a good, quality part is ejected
- Reject part sensing – if an inspection and built-in quality system is present, this sensor registers every occurrence that a rejected part is ejected

The data gathering system functionality was set up as such:

- The prescribed machine metrics of machine cycle time and known down time conditions were entered into the touchscreen during programming
- The data gathering system monitored the machine cycle time by virtue of the input allocated to this function.
- If for any reason, the cycle of the machine is not sensed by predetermined amount of time (typically twice the normal machine cycle time), a downtime event is declared and the built in isolation relay is energized. This event does two things:
    - The isolation relay is wired to the machine directly, in such a way that the operation electrically stops the function of machine and inhibits it from starting

- A pop up screen on the touchscreen is displayed and allows the operator to select from the prescribed list of possible reasons for downtime of the production machine. Once the operator selects the reason, the amount of downtime that has been being counted is logged along with the downtime reason and the isolation relay is de-energized which allowed the machine to be restarted by the operator.

As stated previously, the isolation relay forces the recognition of downtime and forces the operator to respond with proper input before resuming operations can be completed.

Each system has pre-defined logic written using a Boolean logic based program contained in an industrially hardened CPU controller with local inputs and outputs and a self-contained operator touchscreen interface. The Boolean logic program installed in the two controllers is the same for the two systems under study here. The touch screen program, however, varies slightly in that the selections available for “downtime by reason” are respective of the individual machines and contain codes pertinent to each machine.

Appendix 3 is a hard copy printout of the Boolean logic programming code contained within the data acquisition boxes and is the code that not only gathers the production statistics but also the code to decide when to “pop” a downtime

reason page on the touchscreen and also energize the relay to lock out the machine until the proper downtime reason code has been entered.

Appendix 4 is a set of screen shots for the two case study programs. Each case study system utilizes the same background logic but each system has a unique Downtime by Reason pop up screen. These screens contain the respective information that is unique to the particular case study where the downtime-by-reason codes were discovered during the initial interview process.

Case Study 1

MACHINE UNDER STUDY

This first case study company is a one such company that fits directly into the description of the typical "American small business" that uses creativity in equal portions along with 1950's through 1970's vintage equipment. Walking through the plant of this manufacturer, old bicycle wheels hung from the ceiling with springs complete with the bicycle forks used for mounting, demonstrates the essence and creativity used at this business. This company, being the typical American small business, overhead is a nemesis that needs to be fought in every way possible, which includes the use of common materials easily available and low cost. This can be emphasized and is verified by this author having been a small business owner for over 15 years,

The machine under study here is a combination of one off-the-shelf machine and one machine made of a feed device and passive tooling. The first part of the machine is somewhat of a standard spring coiling machine where wire is fed (read that as drawn) into the spring machine and a continuous spring coil is made. A second wire is then introduced (wire drawn in) and a passive tool with a "V" groove forces the second wire into the space of the first spring coil. The second wire is sized so that, when the part is complete, it allows motion to continue to occur within the first spring coil but causes friction to "hold" the first spring coil from recoiling back into the original shape without intervention.

To envision this, just think of the last observed instance when a speaker at a podium moved his or her microphone into position using the flexible metal tubing that attaches to the microphone. This is one of the end products of this company.

Figure 4 is a picture of a sampling of their offerings.

Figure 4 – Picture of Case Study 1 Product Offering

Figure 5 – Photo of Case Study 1 Machine

MACHINE STATE BEFORE STUDY (CURRENT STATE)

As stated previously, an important concept in the pursuit of process improvement is to first know where the state of the machine and/or process is as it exists today – known as the "current state". To paraphrase a Lean precept; "to make good business decisions, good data is needed". (Shahbazi, 2012, p. 27)

Machine/Process Survey Form

Machine/Process Name:	#1 - WD40
Machine/Process ID# (If applicable):	

	Predicted	Simulation Verification Data	Actual Measured
Ideal Cycle Time	4secs		
Ideal Run Rate	15/min		
Nameplate Capacity			
% yield	1/2" wire		
Scheduled Time	7:30-5:00		
Available Time	7:30-5:00		
Up Time	90% [illegible]		
Down Time	10%		
Mean Time Between Failure			
Mean Time Between Repair			

	Downtime Reason Codes	Predicted	Simulation Verified Data	Measured %(By "box")
1	wire snag			
2	time fault – (RESULT)			
3	out of ~~[illegible]~~ loop wire			
4	out of spring wire			
5	kick out arm			
6	Bad wire/material			
7	~~[illegible]~~ power failure			
8	clutch fuse			
9	worn tooling			
10	OTHER			

General maintenance
Lunch
Break
Shift end

Figure 6 – Case Study 1 Metric Form

To capture the machine data, the data gathering box was wired to the machine controller so as to use a spare "normally open" contact of a relay within the motor

controller. As mentioned previously, the system monitors the time between sensing a machine cycle and if that time exceeds a variable set via a field on the touchscreen interface, a relay contained in the data gathering device energizes, thereby locking out the machine start circuit. In this particular case, the machine under study monitored the period of time that the wire feed motor is energized. The machine production cycle time is 4 seconds and initially the timeout period was set for 10 seconds. It was experienced to be a nuisance as the distance between where the data gathering box was located and the machine start button was mounted, the amount of time to restart the system was marginally close to the 10 second period. As such, the timeout period was increased to 15 seconds to eliminate the nuisance timeouts. This increase adds a very slight slant in the data to "uptime" in that the uptime timer continues to count until the timeout period expires. Given that the total quantity of downtime events is relatively small in comparison to uptime and the weekly 50 hour production time period, the extra 10 seconds of uptime per event is negligible.

The interview form shown in Figure 6 indicates the following experience based production data:

- 4 second cycle time
- 15 pieces/min production rate
- Resulting production schedule 50 hours per week (7:30 AM to 5:00 PM with lunch and breaks)
- 90% uptime / 10 % downtime

The interview form also lists the experienced-based downtime, but the operator and the company owner could not put down the predicted amount of time that would be anticipated for each of the reasons given. As a result of this fact, this information could not be included into the model and simulation and only the 90% uptime / 10% downtime figures could be included and is shown in the next section.

MACHINE MODEL AND SIMULATION

Modeling and simulation was a tenet incorporated into this thesis study and its primary use was for validation of the existing process data as attained from observation of the process and/or acquired through interview from the machine operator(s). The use of Arena simulation software which iteratively evaluated the deterministic model in a Monte Carlo type of simulation by using random number inputs contained within the constraints of the known variables of the process resulted in a stochastic model simulation study of the process.

In the case of the first case study machine, the data for production rates and proposed down times were entered into the model created. As it can be seen in the picture and via the interview sheet, the machine is somewhat of a homemade machine and therefore did not have certain theoretical production statistics. Therefore the model output reflected essentially only the production output along with the entered estimated downtime. Appendix 5 is the full model and simulation output run for an iteration of 50 hours - five 10-hour days equaling the work week.

The model itself was constructed using the Arena software's high level packaging functions. In its simplest form, Arena, like many other similar simulation and modeling packages, have the standard rudimentary modeling building blocks such as queues, sources, sinks, etc. The higher end packaging blocks that were used in the simulation for both study cases are compilation blocks using the basic functions but preconfigured for a specific functionality. These blocks are configuration based

and contain selections for reliability, initial or final loss, run/speed parameters. Because these blocks are compiled blocks, they contain the full sophistication normally associated with modeling software however, this sophistication is hid behind the scenes and the configuration data is simply entered into the dialog boxes within the block configuration.

The initial downtime event characteristics were entered into these initial models with the assumption that the interview data was accurate. For the sake of the first model run this assumption did not affect the results as the model run was only used to establish the verification of the interview data.

A visual comparison between the interview sheet (via the production rate) and the simulation does show a close correlation within a reasonable and anticipated variation. The data in the interview sheet shows an “experience rate” of 4 seconds per piece or 15 pieces per minute. A snapshot of the production report of the simulation (see Figure 7), shows a minimum average of approximately 9000 pieces and a maximum average of approximately 45,000. Doing the math using nothing more than the production rate ascertained in the interview, at 15 pieces per minute for 10 hours per day and for 5 days, yields a production value of 45,000. As can be seen, the resulting value from the simulated model runs, which uses the downtime values received from the initial interview, does closely match the theoretical production value.

Unit Summary

Current Units Inside	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	27008.40	17,678.72	8996.0000	45021.0000

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	-20.00	19.63	-40.0000	0.0000

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	26988.40	17,659.09	8996.0000	44981.0000

Figure 7 – Case Study 1 Current State Snapshot of Simulation Output

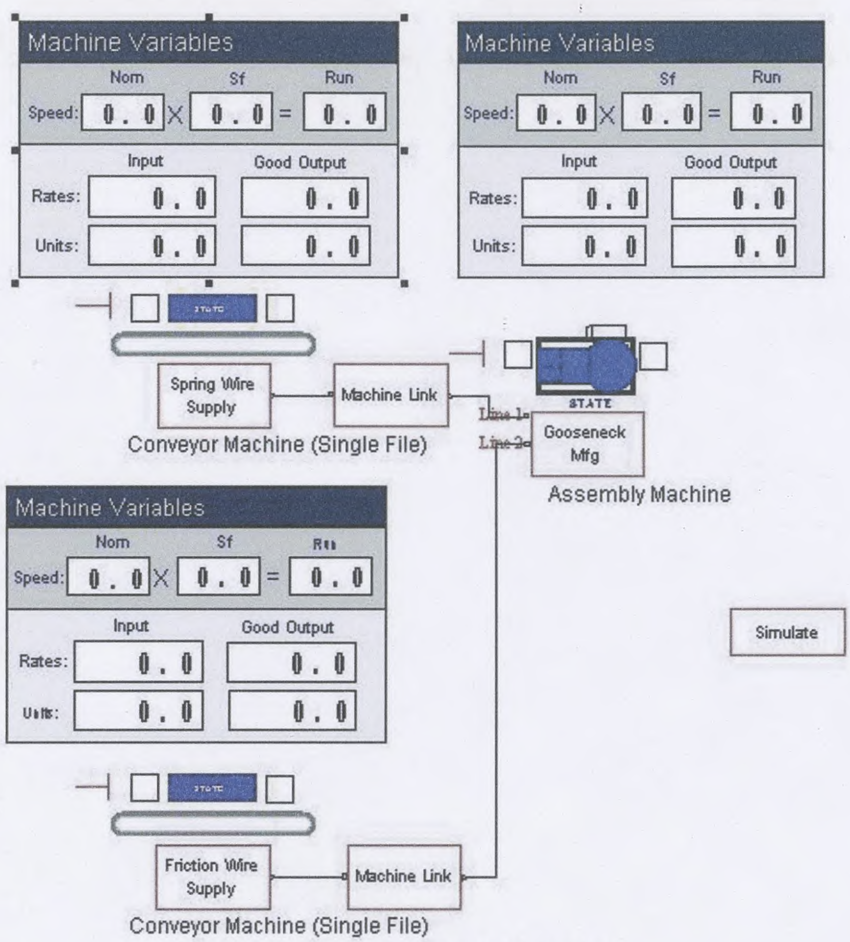


Figure 8 – Case Study 1 Model Graphics

MACHINE DATA ANALYSIS STORY

After the data gathering device was installed and a week's worth of production time was completed (50 hours), the data was extracted from the device and then imported into a spreadsheet. That spreadsheet was sorted and manipulated to put the data into an order that allowed for it to be examined for:

- Downtime by Reason in order of most occurrences
- Trend of run time data
- Uptime and downtime
- Production data

These data points all fit into some standardized Six Sigma formulas that provide an overall piece of data called *OEE* (see the definitions in the Glossary starting on page 6). Table 1 below shows the data from Study Company 1.

Sorted by highest occurrences			
Downtime reason code list	**Downtime Reason**	**Number of downtime events in sample**	% of total events
9	General maintenance / other	35	0.372340426
2	Out of wrap wire	14	0.14893617
0	Wire snag	13	0.138297872
3	Out of spring wire	13	0.138297872
10	End of shift/break/lunch	8	0.085106383
4	Kick out arm	7	0.074468085
1	Time Fault	4	0.042553191
5	Bad wire/material	0	0
6	Power Failure	0	0
7	Clutch Failure	0	0
8	Worn tooling	0	0
			1
	Statistics in Seconds	Statistics in Minutes	Statistics in hours
Total uptime for week	150260	2504.333333	41.73888889
Total Downtime for week	10125	168.75	2.8125
Total uptime percentage	93.69%		
availability in seconds	180000	3000	50
Parts made	43740		
Average rate (parts per unit of time)	0.27271877	16.36312623	981.7875737
Average rate (unit of time per part)	3.666780979	0.061113016	0.00101855

Table 1 – Case Study 1 Production Statistics

The above data and related production statistics were broken down and entered into the standardized OEE calculations to yield the following overall production statistics:

Production Data						
Shift Length	50	Hours =	#	Minutes		
Short Breaks	0	Breaks @	0	Minutes Each =	0	Minutes Total
Meal Break	0	Breaks @	0	Minutes Each =	0	Minutes Total
Down Time	168.75	Minutes				
Ideal Run Rate	15	PPM (Pieces Per Minute)				
Total Pieces	43,740	Pieces				
Reject Pieces	0	Pieces				

Support Variable	Calculation	Result	
Planned Production Time	Shift Length - Breaks	3,000	Minutes
Operating Time	Planned Production Time - Down Time	2,831	Minutes
Good Pieces	Total Pieces - Reject Pieces	43,740	Pieces

OEE Factor	Calculation	My OEE%
Availability	Operating Time / Planned Production Time	**94.38%**
Performance	(Total Pieces / Operation Time) / Ideal Run Rate	**100.00%**
Quality	Good Pieces / Total Pieces	**100.00%**
Overall OEE	Availability x Performance x Quality	**94.38%**

OEE Factor	World Class	My OEE%
Availability	90.00%	**94.38%**
Performance	95.00%	**100.00%**
Quality	99.90%	**100.00%**
Overall OEE	85.00%	**94.38%**

Table 2 – Case Study 1 Production Statistics Detail

There are two comments that need to be made regarding the above data. The first is that inherent into the process of this machine, there is virtually no measurable scrap product which will tend to skew the overall data and yield a higher OEE value. The second is that this machine and process, although fitting this thesis project in terms of the type of equipment, does not lend itself to a large measure increase as the machine OEE is currently at 94.38%. According to OEE.com, "world class manufacturing" has an Availability factor of 90%, a Performance factor of 95% and a Quality factor of 99.9%, when figured together yields an overall OEE of 85% (Vorne, 2012). As it can be seen in Table 2 above, the production statistics data from Study Company 1 is well above "world class" OEE.

One of the premises of this thesis and the initial thesis proposal is, given the vein of improving machine effectiveness, the production data will be analyzed using several tools including charts, graphs, spreadsheet analysis and if the data is plentiful, database data mining techniques will be implemented. However, that last facet (data mining) requires large amounts of data embedded into a database that would allow built-in algorithms contained within off-the-shelf programs such as Business Intelligence modules of Microsoft ® SQL Server. As can be seen in Attachment 2, the pure volume of data is not in great enough quantity that permits data mining algorithms exposing any anomalies and/or any rhythmic or patterns in the production data.

The final major piece of production data analysis that directly indicates issues is the collection of the downtime by reason codes. As mentioned previously, this data is collected by isolating and locking out the production machine when a downtime event is recognized. This event is triggered by the lack of a machine cycle within a predetermined amount of time; a time which is variable so as not to adversely affect the production of the machine by having it so short that an operator cannot get a machine restarted before the collection system locks out the machine again because of a timeout. The lockout does provide somewhat of a guarantee in that the operator needs to acknowledge the downtime event before the machine is allowed to restart.

The production data has been reported using a downtime code and then decoded into the “downtime reason” and then further sorted into descending order of

occurrences. This data is brought into a chart and forms a standard Pareto chart. Figure 9 depicts the downtime by reason Pareto chart for the first study company.

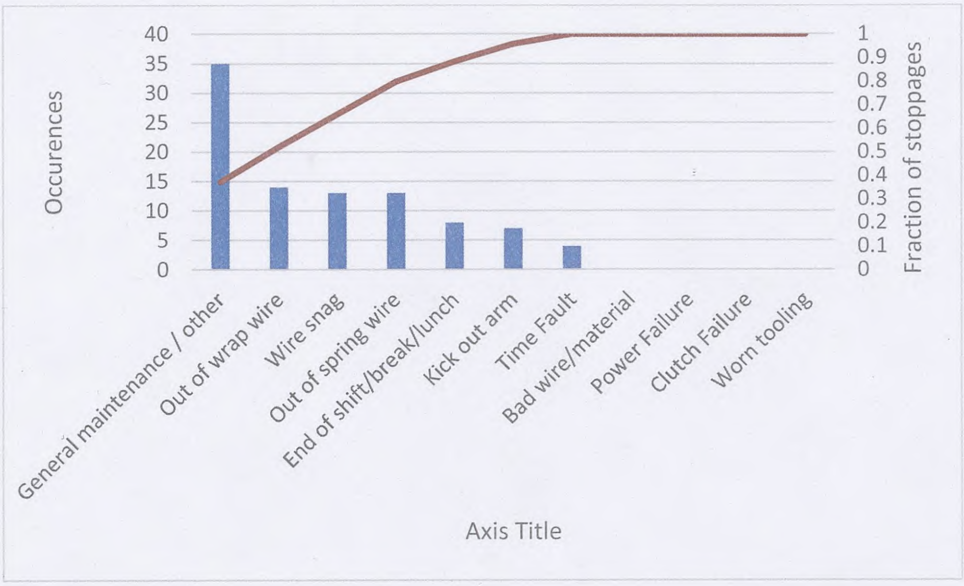


Figure 9 – Case Study 1 Downtime By Reason Pareto

The unfortunate part of this data is that because there needs to be a "catch-all" downtime reason, one really comprised of multiple reasons, usually several unknown or never before experienced reasons, may skew the true downtime data. After seeing the raw data, an interview with the operator resulted in some insight to this seemingly invalid data. During set up, the machine takes several iterations of startup sequences and until the machine reaches steady state, the machine will stop or will be stopped by the operator until the feed wires are running normally.

MACHINE FUTURE STATE POSTULATION

Normally a Pareto chart easily depicts the “low hanging fruit” and allows for an assertion of the corresponding Pareto Principle (the 80-20 rule stating that 20% of the issues will constitute 80% of the reasons). (Bonacorsi, 2011) Here we look for what items constitute 80% of the issues. Looking at the data in Figure 9 above the first four downtime reasons are responsible for 80% of the downtime issues. Two of these items are directly related to each other and that the machine goes down due to the time required to get a new supply of wrap and spring wire.

To that end, a device could be added that turns on a light that energizes when the machine has cycled the equivalent number of times that represents approximately 90% of the use of each of the wire supplies. This would represent two separate lights as the wire supply of each wire is supplied in different lengths on some occasions as well as the consumption of each wire type will vary as they are different in diameters and the corresponding feed rates are different. Once these consumption values are calculated, a cycle counter can be implemented on the data gathering box or on a separate control system.

Alternatively, a sensor may be placed on each wire spool that detects a low level of supply of the feed wire. The sensor would simply light a stack light to indicate to the operator that the respective spool will need to have a new supply of feed wire ready to be changed imminently.

This proposed system will warn the operator when the wire supply is low and he/she can get the new supply of feed wire in place and close to the place of usage, thereby reducing the overall time the machine needs to be down to restring and set up the machine with the new spool(s) of wire.

In an attempt to prove out the postulated improvements before they are physically implemented, an updated model including these improvements are simulated. Since the initial model and simulation completed at the onset of the machine study did not include any of the downtime reasons in the initial configuration of the model (particularly in the reliability configuration) and given the acquired data depicting the overall resulting uptime and downtime, a second model and simulation was executed using this information to validate the actual run data against the failure data as acquired by installed new system now included in the model. The following figure displays a portion the simulation data output that shows this updated model. The full model and simulation report is contained in Appendix 6.

Unit Summary

Current Units Inside	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	3914.40	2,457.03	1463.0000	6392.0000

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	3914.40	2,457.03	1463.0000	6392.0000

Figure 10 – Case Study 1 Future State Snapshot of Simulation Output

MACHINE FUTURE STATE IMPLEMENTATION

Stated above, due to the inability for the timely implementation of the actual postulated changes, it is easily seen that an implemented methodology that would warn an operator of an impending outage of raw material would prevent the machine from going down while unattended thus causing unnecessary downtime.

With a calculation entered into the data acquisition processor that tracks the amount of each raw material used for each unit produced, along with an entry of the amount of wire initially contained on the raw material spools, the system would be able to warn the operator via a buzzer and light when the system gets low. This would allow the operator to get new spool(s) ready for re-threading into the production machine well before the machine actually runs out of supply.

FUTURE STATE DATA ANALYSIS

Due to the fact that the implementation of the postulated changes that would lead to a future state of the machine is lengthy and would cause downtime to the machine to deploy, the changes are being effected and will be gathered at some future date for archiving purposes and future publications. However, the proof will need to be based on reduction shown in the difference between simulations.

As shown in Figure 7, an initial model and simulation was completed based on the data acquired during the initial interview process but due to the fact that the exact data had never been acquired by the company, there was no documented results that had specific details on the downtime reasons and how they impacted the production data, but rather just the knowledge gained from experience through operating the machines resulted in the known reasons for downtime and a “gut feeling” what might be the major event.

After the initial investigation and data gathering period was completed, the resulting statistical data could now be used as inputs to the model for use as the actual downtime events with the resulting weighting and rating of their impact on production data.

As part of the future state, the postulated improvements would almost entirely eliminate the largest contributor to downtime data. As a validation of this postulation, an updated model and simulation was completed. This updated model included the

improvements comprised of the reduced amounts of the two wire out faults which was predicated through the proposal of warning the operator of an impending wire out situation and allowing him/her to get a new supply ready for a quick changeover.

Figure 11 shows the simulation run with the above described scenario. The full model and simulation report is contained in Appendix 7.

Unit Summary

Current Units Inside	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	4777.40	3,002.25	1736.0000	7780.0000

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	4777.40	3,002.25	1736.0000	7780.0000

Figure 11 – Case Study 1 Future State Snapshot of Simulation Output With Posulated Changes

The improvement between the observed machine data and the corresponding model and simulation to that of the model and simulation can be seen to validate the proposed changes to the process. Figure 10 indicates a simulated Total Units Processed Maximum Average of 6392 while the simulation with the proposed improvements included (Figure 11) show a value of 7780 parts. This represents an increase in production of 21.7%.

By virtue of these increased production amounts the above data represents an improvement in downtime that would correspond to the (near) elimination of the

downtime events shown in Table 2 and Figure 9 and the corresponding increase in Total Units Processed. This improvement in production was represented in the model and simulation by eliminating the amount of the total downtime that was caused by the top two downtime reasons that were specifically defined which represented approximately 25% of the total downtime of the machine. The Pareto chart in Figure 9 shows this detail. Although the top reason is for General Maintenance / Other, this particular category is a “catch-all” and is not defined in enough detail to be able to postulate a method to eliminate the downtime related to this category.

SUMMARY OF CASE STUDY 1 RESULTS

Overall, Case Study Company 1 was successful in that, strictly speaking, the premise of this thesis and its application was implemented with the results showing a corresponding increase in productivity. It was distinctly demonstrated through the final simulation output that the implementation of the proposed changes would, in fact, increase productivity of the existing machine.

Although the case study improvement was proved through simulation with the data from the final updated model and simulation validating the process improvement postulation, every confidence along with logical practicality will prove out that the actual case will follow the model and simulation.

Case Study 2

MACHINE UNDER STUDY

This second case study company is a similar in makeup to the first case study, albeit larger in size (relatively speaking), stature and organization. However the company certainly uses 1950's through 1970's vintage equipment and the air of environment certainly smells of lubricant and coolant as the in-house machines work hard producing their end product. The machine itself is, in fact, a 1960's vintage cold heading machine. A cold heading machine takes a piece of steel wire and, for lack of a better term, “smashes” it into a specific fastener shape.

By the very nature of this machine, there is absolutely no automation and it is run by a motor driving a cam. As the cam rotates, different parts of the machine operate on the feed wire. The final result is a shaped piece of wire that is destined to be a fastener of one type or another (screw, rivet, etc.).

The machine shown in Figure 12 and 13 are photos of the production machine with Figure 12 showing the machine proper and Figure 13 showing the wire feed into the machine. This wire feed is the “fodder” that gets fed, cut and formed into a fastener.

Figure 12 – Photo of Case Study 2 Machine

Figure 13 – Photo of Study 2 Machine Wire Feed

As shown in the lower right of Figure 12, a small inductive proximity switch has been mounted and wired into the data gathering box. This proximity switch senses a machine cycle as this device looks at a shaft that “pogoes” in and out, once for each cycle of the machine. As described in the Study 1 machine, a timeout period has been entered into the touchscreen of the data gathering box and if the box does not see a machine cycle before the expiration of the timeout period, the system stops accumulating uptime, starts accumulating downtime, energizes a

relay that locks the machine out preventing a restart and a screen pops up that lists the standard downtime reason codes. When acknowledged, each acknowledgement increments the downtime reason code counter by 1 and then releases the interlock relay thereby allowing the operator to restart the machine. At this point, the data gathering box begins accumulating uptime once again.

Again, as was in the first case study and as was the premise of this thesis this company truly desired to know their processes better. However, they just do not have the direct technology nor infrastructure to be able to collect this data without dramatically affecting the productivity of the operators. Any manual effort made towards this endeavor is ineffective with operator tasks become more clerical than that of production operator.

MACHINE STATE BEFORE STUDY (CURRENT STATE)

During the initial interview, study company 2 provided current state data representing experiential data for the machine. This company was exhubarant to have the study done as the resulting information from this practice is a program that they have been researching and trying to figure a way to implement on their own. However, there are several facets that make the interview data approximate and variant. Figure 13 below is a scan of the production data form from the interview.

Machine/Process Survey Form

Machine/Process Name:	Heading
Machine/Process ID# (if applicable):	

	Predicted	Simulation Verification Data	Actual Measured
Ideal Cycle Time	1.67pc/sec		
Ideal Run Rate	100ppm		
Nameplate Capacity			
% yield			
Scheduled Time	10 hrs		
Available Time	10 hrs		
Up Time	50%		
Down Time	50%		
Mean Time Between Failure			
Mean Time Between Repair			

	Downtime Reason Codes	Predicted	Simulation Verified Data	Measured %(By "box")
1	2nd punch chipped/broke			
2	1st header broke			
3	Die cracked/chipped/broke			
4	Die loaded up/toolmaker repair			
5	Out of wire			
6	Job complete/setup			
7	Complete size changeover			
8	1st header spring broken			
9	Die pin chipped/broke			
10	Machine broke/maintenance req.			

Figure 14 – Case Study 2 Machine Metric Form

The issue with the above interview data is primarily due to the fact that this cold heading machine can be set up to operate and manufacture parts that are a couple thousands of an inch long to parts that are a couple inches long. As such, production rates are going to vary accordingly. This variation is because the amount of time required to feed a very small length of wire is going to vastly vary from that of a feed of a significantly longer piece of wire.

In addition, the downtime information was received as a result of the operator offering to the company's operation manager what his experience (day to day exposure to the machine) is for the typical faults.

As was the circumstance in the Case Study 1 company, the downtime reasons received in the interview did not come with the typical percentage of downtime related to each reason that might have been estimated through years of experience with the machine operation. As such, they were not able to be included into the model and simulation but rather the fixed 50% downtime was entered as the expected downtime in the model and simulation run.

Appendix 2 contains the full report of the completed model and simulation for the current state (as discovered) machine for this study case. A snapshot of the production statistics from that report, is shown below in Figure 15.

Unit Summary

Current Units Inside	Average Value	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Good Units Produced	Average Value	Half Width	Minimum Average	Maximum Average
Cold Formining	237998.50	965,649.65	161999.0000	313998.0000

Total Units Lost	Average Value	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Units Processed	Average Value	Half Width	Minimum Average	Maximum Average
Cold Formining	237998.50	965,649.65	161999.0000	313998.0000

Figure 15 – Case Study 2 Current State Snapshot of Simulation Output

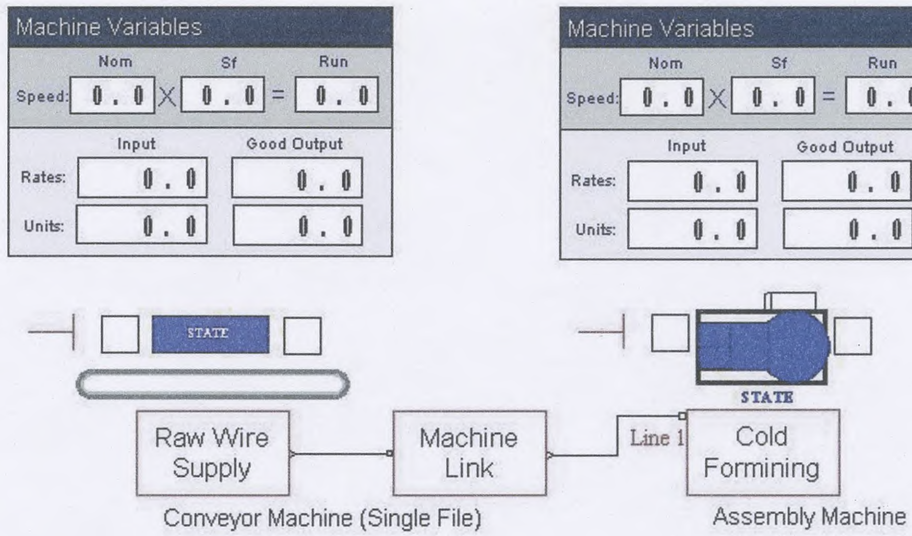


Figure 16 – Case Study 2 Model Graphics

This machine model was configured using the experiential data taken from the interview and the simulation run to match the actual work week. Because the downtime data occurrence type (uniform, exponential, etc.) was not readily known by the owner and/or operator it was put in as the overall expected downtime rate of 50%, the figure given in the interview with a 20 minute time to repair.

To verify this model, the production rate given in the interview is used to calculate a raw production figure. Based on the average 100 parts per minute and a 50 hour work week, a "perfect" work would yield 300,000 parts. Based on the data shown in Figure 15 above, the model and simulation does hold up and match with what should be a typical 50 hour run.

MACHINE DATA ANALYSIS STORY

While extracting the data from the second case study machine, the company owner and an operator not directly associated with this particular machine, but familiar with its operation, both quipped about the difficulty of the product that was running on the machine. It would turn out, as the data below will show, the machine production data did not represent the typical machine operating parameters that was expected from the original interview.

As was the situation in case study 1, the data gathered for this machine was done over a 50 hour period and the raw data logs were brought into a spreadsheet and sorted to look for the same downtime by reasons, trend of run data, uptime and downtime and overall production counts. Again, these data points are then plugged into the Six Sigma OEE formula. Table 3 below shows the sorted study data.

Sorted by highest occurrences			
Downtime reason code list	**Downtime Reason**	**Number of downtime events in sample**	% of total events
5	Job Complete/Setup	74	0.564885496
0	2nd Punch chipped/broken	52	0.396946565
10	End of shift/break/lunch	4	0.030534351
9	Machine broken / maintenance required	1	0.007633588
1	1st header broken	0	0
2	Die Cracked/chipped/broken	0	0
3	Die loaded up/toolmaker repair	0	0
4	Out of Wire	0	0
6	Complete size changeover	0	0
7	1st header spring broken	0	0
8	Die pin chipped/broken	0	0
	Statistics in Seconds	Statistics in Minutes	Statistics in hours
Total uptime for week	41365	689.4166667	11.49027778
Total Downtime for week	110273	1837.883333	30.63138889
Total uptime percentage	27.28%		
availability in seconds	180000	3000	50
Parts made	71528		
Average rate (parts per unit	0.471702344	28.30214062	1698.128437
Average rate (unit of time p	2.119980986	0.035333016	0.000588884

Table 3 – Case Study 2 Production Statistics

After taking the compiled data in Table 3 and inserting the appropriate production statistics into the OEE formula, the results are shown below in Table 4.

Production Data						
Shift Length	50	Hours =	#	Minutes		
Short Breaks	0	Breaks @	0	Minutes Each =	0	Minutes Total
Meal Break	0	Breaks @	0	Minutes Each =	0	Minutes Total
Down Time	1837.883333	Minutes				
Ideal Run Rate	100	PPM (Pieces Per Minute)				
Total Pieces	71,528	Pieces				
Reject Pieces	0	Pieces				
Support Variable	**Calculation**				**Result**	
Planned Production Time	Shift Length - Breaks				3,000	Minutes
Operating Time	Planned Production Time - Down Time				1,162	Minutes
Good Pieces	Total Pieces - Reject Pieces				71,528	Pieces
OEE Factor	**Calculation**				**My OEE%**	
Availability	Operating Time / Planned Production Time				**38.74%**	
Performance	(Total Pieces / Operation Time) / Ideal Run Rate				**61.55%**	
Quality	Good Pieces / Total Pieces				**100.00%**	
Overall OEE	Availability x Performance x Quality				**23.84%**	
OEE Factor	**World Class**	**My OEE%**				
Availability	90.00%	**38.74%**				
Performance	95.00%	**61.55%**				
Quality	99.90%	**100.00%**				
Overall OEE	85.00%	**23.84%**				

Table 4 – Case Study 2 Production Statistics Detail

What can been see from the above data tables is that first, there was no scrap that was reported. Because any scrap for this process only shows up when a failure of the machine occurs, if a failure such as a broken punch is discovered immediately, the amount of scrap is almost negligible. A piece of information that jumps off the page is the very low OEE value of approximately 24%. This is due to the very low Availability factor and the low Performance factor.

The data available for this period was tainted to a degree in that the product that was being set up and run during the period was, as quipped about by the operator

and owner, extremely difficult to set up and run as this particular product takes a significant amount of "tweaking" to get the system operating in a normal capacity.

However, the downtime by reason codes did indicate with relative certainty where the main issues were. Once again, using a Pareto analysis of the downtime reason codes results in the chart shown below in Figure 17.

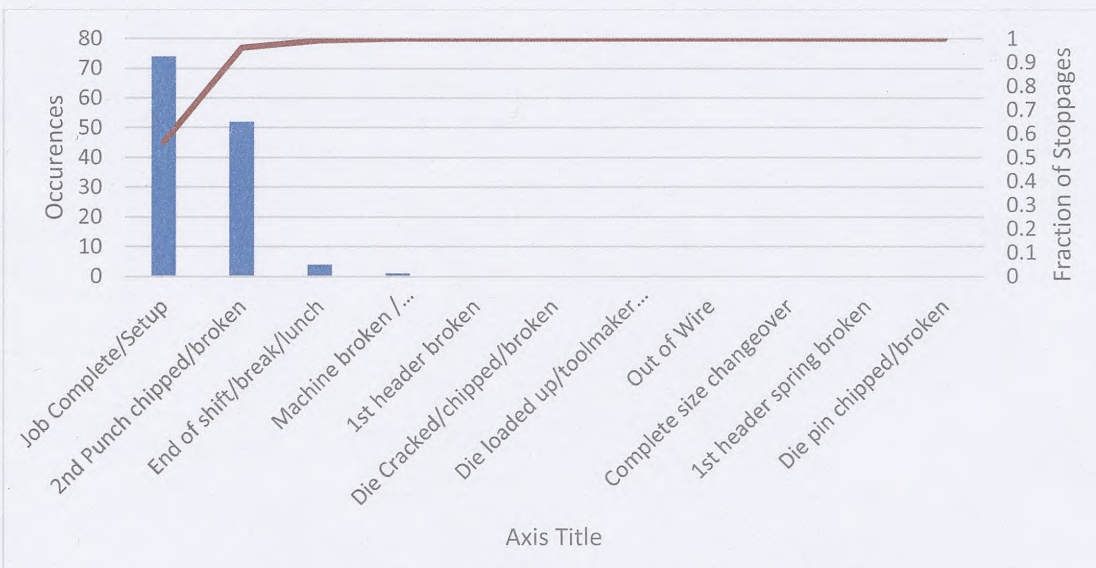


Figure 17 – Case Study 2 Downtime by Reason Pareto

The Pareto analysis shows that the first two reasons were responsible for over 90% of the downtime reasons. Given the duration of the first phase of the study and given the fact the product being run during this time frame is extremely setup intensive, the result yields a very high setup downtime reason, in fact, 56% in the above data.

The next highest percentage downtime reason is a broken or chipped second punch. There is no way to prevent this reason but there is a way to prevent this downtime event from making a large amount of scrap.

MACHINE FUTURE STATE POSTULATION

Armed with the above information and after further conversations with the machine operator it became clear, that the notion that because the machine has no intelligence or extraneous sensors and therefore no ability to sense when the broken punch event occurs, the machine will continue to run when this downtime event occurs and will continue to produce scrap product with a broken or chipped punch. A means can readily be developed to detect this event and, through a modification added to the data acquisition box used for this thesis study, halt the machine using the existing machine stop interface within a single cycle thus preventing what would normally be a large percentage of scrap product.

Because the second largest downtime and scrap causing defect is broken or chipped punch, the proposed change to the process is to install a device that can detect when the punch is broken. The owner and operator indicated that this could be done by a device that measures an “over stroke” condition. This device would need to be adjustable so that it could be set up based on the needed stroke to make the product currently being run (with each product being a somewhat unique stroke length of the cam operated cold heading press).

Using a conductive probe that is mounted on micrometer (driving a fine pitched screw) actuated stage allows for accurate placement of the probe inside the stroke motion positioning it such that the probe stops just short of striking a permanently mounted contact block. The micrometer adjustment allows the operator of the

machine to be able to adjust and set the probe contact based on the actual stroke of the cold header press.

The hard-mounted button stop is electrically grounded while the "pogo pin" probe is wired to the PLC's 24VDC power supply through a pull up resistor. If the press ever over-strokes because of a broken punch, the adjustable pogo-pin probe tip will contact the button stop and connect the pull up resistor to ground and cause the PLC input to present a 0VDC logic condition. The PLC is programmed to react with a "stop" command based on this logic 0 condition. Since the data acquisition box already has the stop interface wired into the cold header machine, this new condition is simply a software change.

Figure 18 depicts the schematic circuit for the punch break detector (as described above).

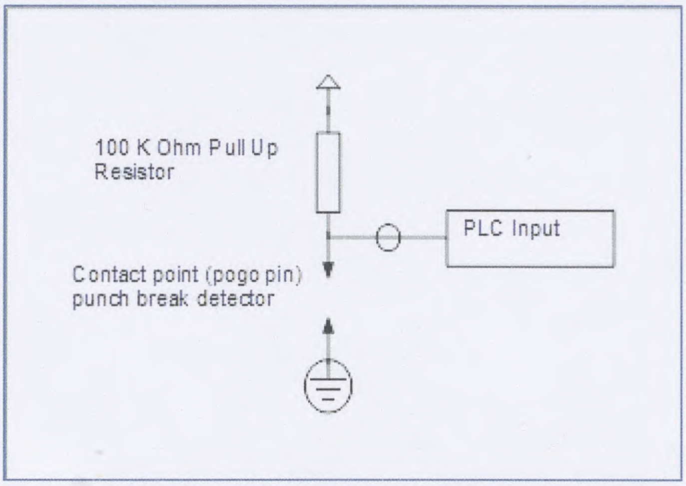


Figure 18 – Circuit Schematic of Punch Break Detector

Just as in the circumstance of Case Study 1, the first simulation performed was completed using the interview data and did not contain the downtime data as part of the simulation. Once the initial data was gathered, an updated model including these downtime reasons and the percentages entered in was executed through simulation. Figure 19 shows an updated model and simulation with the faults captured during the data acquisition period. The reliability data for the second model run was entered as time between failures to mimic the data that was collected and analysis showed these as a function of run time.

Unit Summary

Current Units Inside	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	84823.40	60,021.79	22573.0000	143669.0000

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	23.8000	15.76	9.0000	40.0000

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	84847.00	60,037.34	22582.0000	143708.0000

Figure 19 – Case Study 2 Future State Snapshot of Simulation Output

MACHINE FUTURE STATE IMPLEMENTATION

In the example of the Case Study 2 machine in comparison to Case Study 1, the machine's large issue is not directly related to downtime but rather the amount of scrap material generated as well as wasted operations time when the system continues to operate with a broken 2nd punch.

The future state, as mentioned above, utilizes the data acquisition box that already incorporates a stop circuit to the cold heading machine. With the proposed recognition of an "over stroking" head related to a broken punch, the process improvement results in the stopping of the system upon the recognition of the broken punch.

Because the production machine does not have any apparatus to select good and rejected parts, the model and simulation does not incorporate "good" or "reject" part production statistics. However, the implementation of broken punch detection will have a large impact on this machine as downtime is only a portion of the issue having to do with a broken punch.

FUTURE STATE DATA ANALYSIS

Just as was explained in Case Study 1 above, the case study company did not have the ability to implement the recommended (postulated) changes due to scheduling conflicts. Even without evidentiary support, it can still be easily seen that a method to stop the machine immediately upon the recognition of the major faults would prevent the machine from going down while unattended. This situation, when not prevented, would be unnecessary downtime and a loss in machine availability and production.

With the addition of the punch break detection sensor, the system would be able to stop the machine and warn the operator via a buzzer and light when this specific downtime event occurs.

Without the future state data in hand which would have been available after the successful installation of the required components, a secondary simulation was run with the major downtime causes removed from the model. The following data in Figure 20 shows the improvement in production statistics. This cold forming units produced in Figure 19, (84,823) compared to the same data point in Figure 20 (99426) shows a 17% increase in production. Additionally, through the use of the punch detection system and the related operator alert system, the uptime of this machine could be increased from the existing 27% shown in Table 3 to what would be a typical 80 to 90% of uptime seen in similar production equipment and common

in world class machinery OEE components. This alone represents over a 3 fold increase in productivity.

Unit Summary

Current Units Inside	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	99426.00	65,806.53	30446.0000	164398.0000

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	19.2000	10.87	7.0000	30.0000

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	99445.00	65,817.54	30453.0000	164428.0000

Figure 20 – Case Study 2 Future State Snapshot of Simulation Output With Postulated Changes

Running the model and simulation to indicate an improvement in downtime is not the true savings in the future state implementation of Case Study 2. In this particular case, the model and simulation shown above in Figure 20 does show an increase in productivity, but does not truly reflect the savings in this machine with the proposed changes.

Of particular importance to the future state implementation and the related broken punch detection is that it will prevent the manufacturing of scrap material. As mentioned above, preventing downtime through the detection of a broken punch is only half of the future state improvements to the machine. Because the cold heading machine itself is blind in regard to the aspect of the quality of the product and with no ability to have an immediate inspection sensor relaying the quality of a product

and segregating them accordingly, the future state implementation becomes doubly critical as it causes an immediate end to the production of bad (rejected) product.

Prior to this implementation, without a mechanism in place to prevent and/or stop the machine from making bad product coupled with one operator running multiple production machines, a machine with a broken punch would typically run for extended period of time. This situation poses a double hit as not only does the machine continue operation in making bad product yielding potential pounds of scrap material, even more importantly, the machine would continue to run wasting vital production time that would otherwise be used to keep scheduled production up. Therefore the extended time running with a broken punch results in double loss in that it results both in scrap material and wasted run time making bad product.

So, it can be clearly seen, that the implementation of the future state is a threefold net positive result in:

1. Reducing downtime
2. Reducing scrap material
3. Eliminating wasted production time and activity of the machine that might otherwise be used to continue making required production filling a tight production schedule and customer needs.

SUMMARY OF CASE STUDY 2 RESULTS

Just as in Case Study 1 the future state implementation of Case Study Company 2 was successful in that the premise of this thesis and its application was successfully implemented resulting in a corresponding increase in productivity through the lack of downtime as well as, in particular in Case Study 2, the reduction of scrap material and wasted operation of production machine making scrap material.

Although the case study improvement was proved only through simulation, it can clearly be seen and logically follows that any method that reduces downtime and reduces scrap will result in an overall improvement in machine production statistics and will justify the actual implementation that follows from the result of the model and simulation.

SUMMARY AND CONCLUSIONS

Although the two case studies started out with the same outcomes in mind, two different kind of discoveries were had.

An unexpected side effect of the thesis study was observed in the first case study company. In this case, it is possible that the downtime data may be tainted in a sort of way that a full and unabated data set might have otherwise been observed. This phenomenon, unlike a blind study, lets the operators know that there is a device present and is looking in at their production, operations traits and techniques, and to their own admission, knowing they were being observed, had done things to keep the machine running more efficiently where the production data would have normally indicated more frequent downtime reasons.

As an anecdote that proves that the larger companies use the standardized programs available to companies that have the budgets and wear-with-all to be able to build on the technology platforms inherent in their large dollar machines, a recent field service start up trip of an engineer for a large automated line shows this fact.

The engineer was onsite in China performing a startup for the deployment of a full production line installation for a multi-billion dollar company. This company, knowing that programs such as Lean and Six Sigma expose and help identify problem areas in production, had implemented a full Manufacturing Execution System (MES), taking advantage of nine production machines networked together with fully capable

PLC (programmable logic controller) based systems. This integration, which is tightly coupled with a data system, utilizes high end techniques such as data mining methods on the large catalogs of data to check SPC data, as well as trends in the process control as a means of direct traceability of production data for governing agencies such as the FDA. In this particular anecdote it is shown and noted that the overall strategy is the same as the premise of this thesis with the execution done via the control and network architecture installed within the equipment base as opposed to a small “bolt on” box that was used in the two case studies done in this thesis.

Although the data gathered was relatively short in duration, the changes recommended from the analysis are based on the related volume of data. The premise of this thesis was not in the fact that the two case studies were improved based on the data that was acquired, but rather through the manner and means of being able to apply a designed methodology.

Moreover, the overarching concept is not only that of process improvement but in the fact that the process can be completed simply and inexpensively by small businesses that historically cannot afford the higher end machinery that have the ability to collect data. The ability to use various applied computer science techniques now available coupled with a dedicated programmable data acquisition box is the key factor to the success of this thesis’s premise.

Having been in the industrial control system arena for this author’s 35 year career, the experience and practical knowledge gained during this period was instrumental

in the foundations and implementation of this thesis study. Given this premise and then coupled with the technical knowledge gained through all the college studies from the initial technical studies and culminating in the advanced studies at CSU, were all taken with a pointed and targeted vision in mind. Also having firsthand experience in owning a business directly in this industry has revealed a rather large gap in the abilities of companies to be able to use the world renowned and proven programs such as Lean and Six Sigma. The bottom line of being able to partake in these programs is the technology on the factory floor.

The initial premise of this thesis was that the gap in apparent technology on the factory floor between companies with sales revenues in excess of $20 million and those between $2 and $20 million is vast. The larger companies, when purchasing capital equipment, can afford to invest in equipment that has the onboard technology that directly lend to the ability to implement the Lean and Six Sigma programs. These technologies have the inherent ability to extract and analyze production data and statistics.

The entirety of the thesis is the culmination of several facets of electronics, programming, engineering, and computer science. The result of the study which relies on these disciplines is data which is further analyzed through calculations performed through a spreadsheet and results in OEE, Yield, Uptime, Downtime, Performance, Quality, Productivity, etc. The full analysis does not rely on a level of higher end formulas but rather utilizes straightforward and industrially proven

calculations that rely on the quality of the gathered data and also utilizes proven scientific methods. All of these facets comprise the major premises of the thesis.

Through the application of techniques acquired over the above mentioned 35 year career, knowledge and technologies gained in Associate and Baccalaureate studies along with a newly acquired knowledge base in Master's level Modeling and Simulation and networking and database techniques, the methods posed can be applied to help analyze and find potential inefficiencies.

To that end, the steps described as the research methodology was to:

- choose a process in need of improvement,
- acquire preliminary theoretical production data,
- model and simulate the process to validate the theoretical data,
- measure the process data using CPU based equipment,
- analyze the data using standardized techniques including Excel charting and database data mining tools when applicable,
- propose process changes based on the analyzed data,
- model and simulate the proposed changes,
- implement changes,
- acquire data from changed process,

- compare proposed modeled process data to acquired data to validate the changes

Through the above data and related analysis, it can clearly be seen that the processes of small to medium sized companies can be improved upon through the use computer based modeling and simulation coupled with implementation of low cost data gathering equipment. .

RELATED DISCOVERIES

Part of the selection process for the case study companies was to do a sales pitch of sorts. It was very difficult to make arrangements to get into the company for the second case study and once the arrangements were made, the interview was done with the operations manager and the owner of the company. Once onsite the first thing the president said was “if this is a sales gimmick, I am done and I don’t want any part of this”. The tone was set for the meeting it seemed. Immediately after the president and the operations manager were seated the presentation began. After the first fifteen seconds, the president announced loudly, “STOP”. At this point it seemed the interview and presentation was over. Instead the president invited two more operations people into the room and after they were seated the presentation was restarted. About another thirty seconds in, once again the president yelled “STOP” and, once again he invited two more people to the table, with these people being responsible for the quality department. The presentation restarted.

At the conclusion of the presentation, the head of the quality looked straight at the president and stated that the proposed program was “exactly” what she had been trying to implement but could not find a method, device or company to be able to do this. The president of the company responded and asked if there was any way that this study (or a way even after the study) that his entire plant, consisting of more than twenty machines, could be done with the proposed method and equipment.

This one well received offer was justification and validation that the premise for this thesis is indeed needed in the space for which it was proposed and designed.

REFERENCES

Bonacorsi, S. (2011, November 8). *New to Six Sigma - Step-by-Step Guide to Using Pareto Analysis*. Retrieved June 21, 2015, from PEX Process Excellence Network: http://www.processexcellencenetwork.com/lean-six-sigma-business-transformation/articles/using-pareto-analysis-to-divide-and-conquer-impro/

Mike George, D. R. (2004). *What is Lean Six Sigma?* New York: McGraw-Hill.

Shahbazi, S. S. (2012). *The McGraw-Hill 36-Hour Course (R) Lean Six Sigma.* New York: McGraw-Hill.

U.S. Census Bureau. (2012, August 2012). *Statistics about Business Size (including Small Business) from the U.S. Census Bureau*. Retrieved May 31, 2015, from United States Census Bureau: http://www.census.gov/econ/smallbus.html#RcptSize

Vorne. (2012). *World Class OEE*. Retrieved June 21, 2015, from OEE.com: http://www.oee.com/world-class-oee.html

APPENDIX 1

Plan Brochure

Gather the Data Once Again

6. As in step 3, the machine is operated once again for a period of typically two weeks with the data gathering device still in place.

Compare and Celebrate the Productivity Increase

7. At the end of the testing period the data gathered in step 6 above is compared to the original process data that was acquired in step 3 and that of the postulated improvements demonstrated in the model and simulation for the calculated improvements in step 5. The comparison here should indicate first a resemblance to the modeled data and more importantly, proof of the proposed process improvements.

SUCCESS!

COLUMBUS STATE UNIVERSITY

TSYS School of Computer Science

THESIS STUDY BY BRIAN ROMANO

Phone: [illegible]
E-mail: [illegible]

THESIS STUDY BY BRIAN ROMANO

Small Business Machine Process Improvement - A Computer Science Assisted Strategic Implementation of Lean Principles

The Plan

7 Step Process

Define & Document

1. Define and document the process through an interview. This starts the process by defining the machine process parameters along with the issues that hamper the process.

Define & Document

Model and Simulate

2. Model and Simulate the machine process to validate the interview data.

Data Acquisition

3. A microprocessor based data gathering box will be connected to your machine process. Depending on your exact process, up to three sensors will be connected; Machine cycle, Good parts, Reject parts. The controller will sense downtime through the lack of a machine cycle sensor and when a pre-determined amount of downtime has been accumulated an interlocking relay that will stop the machine from running until the operator selects a standardized downtime reason (as defined in the interview process). This "box" will gather data for a pre-defined period, typically around 2 weeks.

Existing Process Data Gathering

Crunch the Data/Find the holes

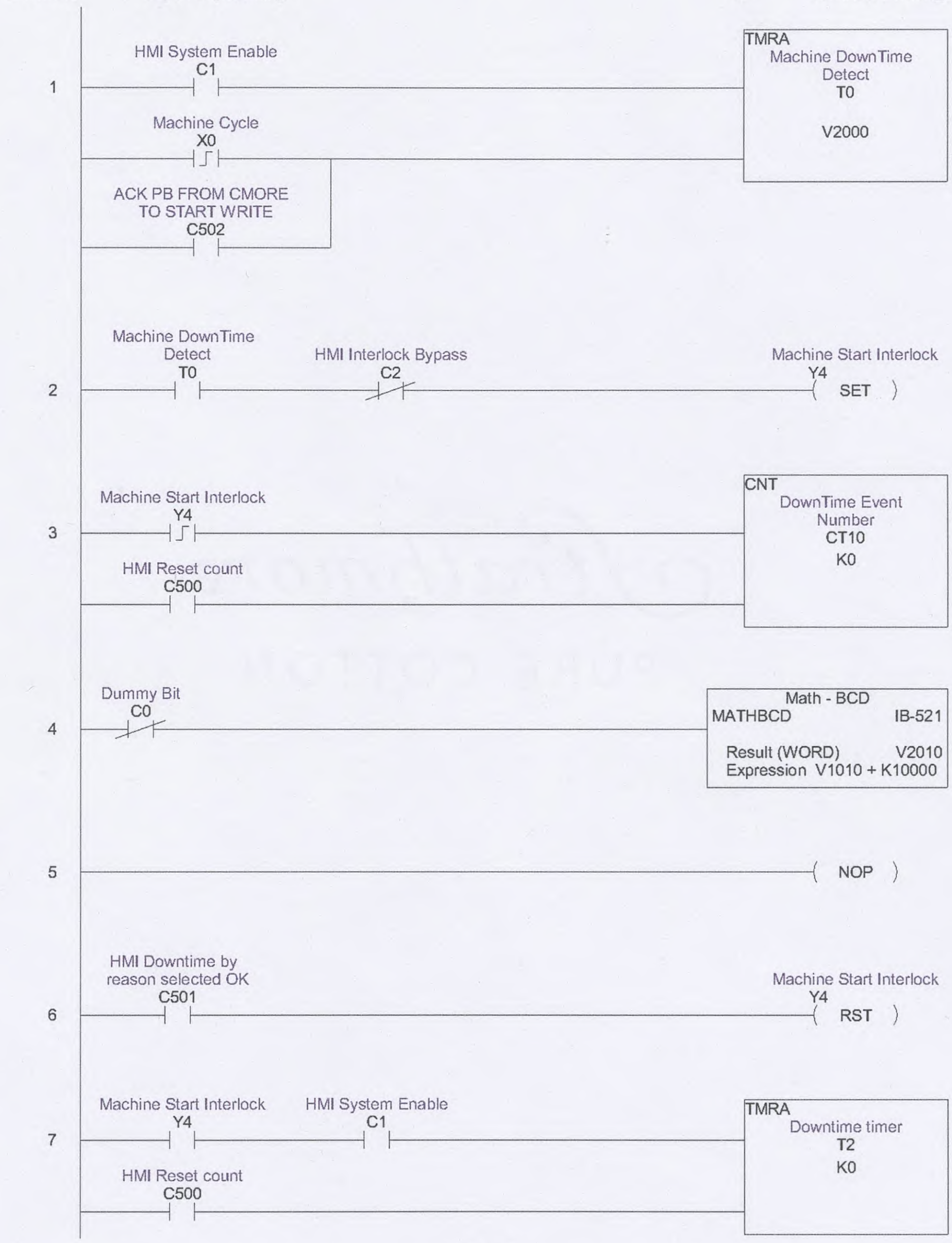
4. A series of number crunching techniques, which may include data mining, pattern seeking and other similar procedures to rate the issues and find potential otherwise unrecognizable patterns (such as "on the third Friday of every month, the availability of the machine drops to a monthly low)

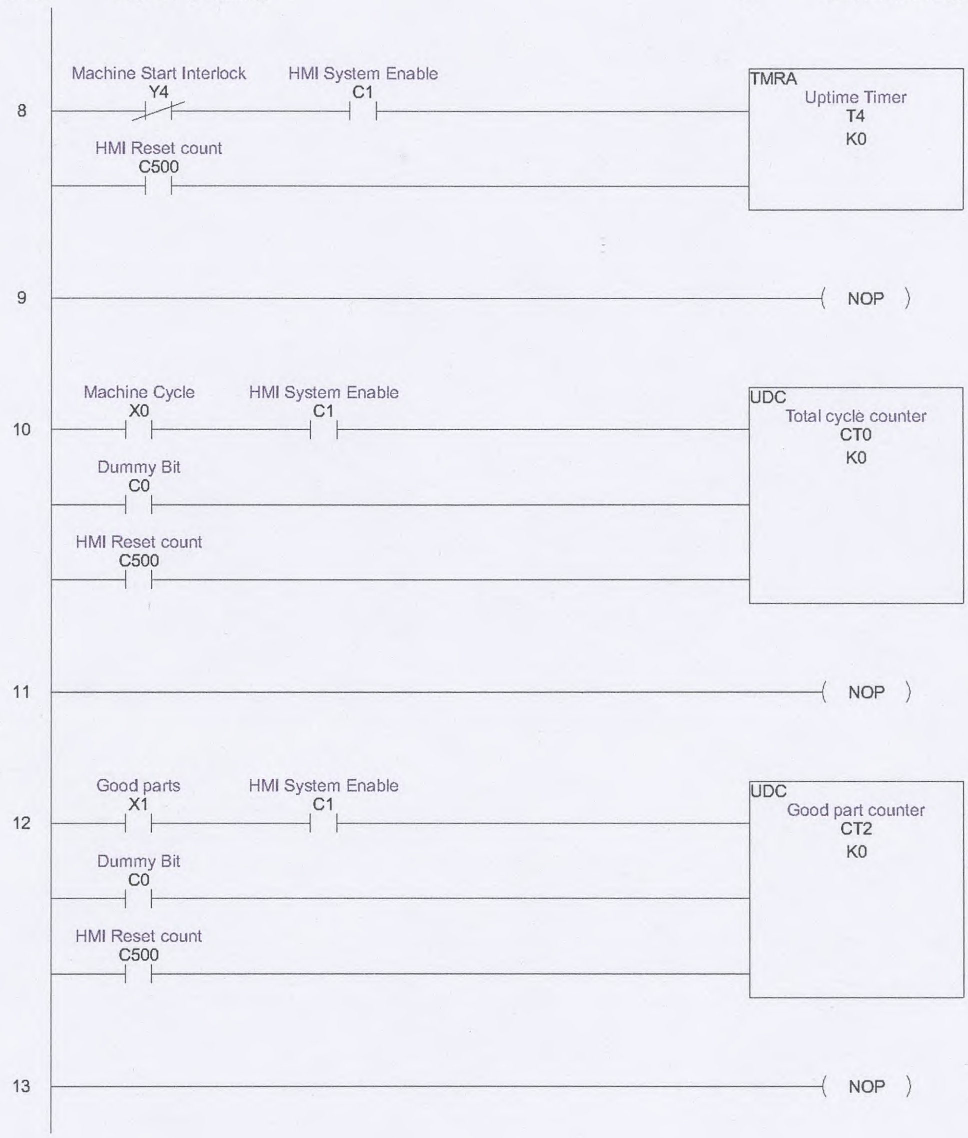
Propose Process Changes and Test

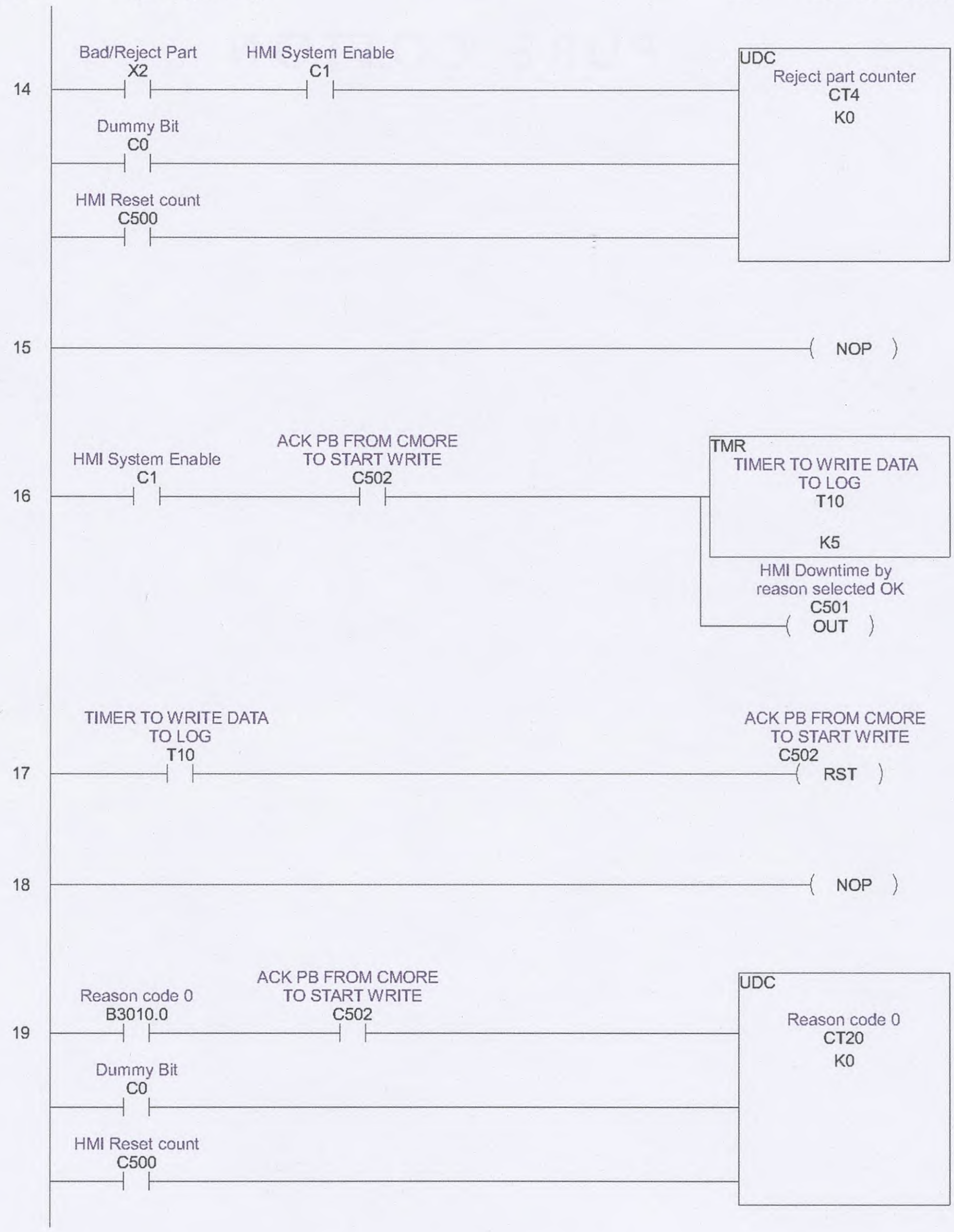
5. After the holes in the process discovered above, process changes will be recommended and these changes will be tested using the original model and simulation, but with the proposed changes plugged in. If the changes prove out in the simulation, the changes are implemented on to the machine process.

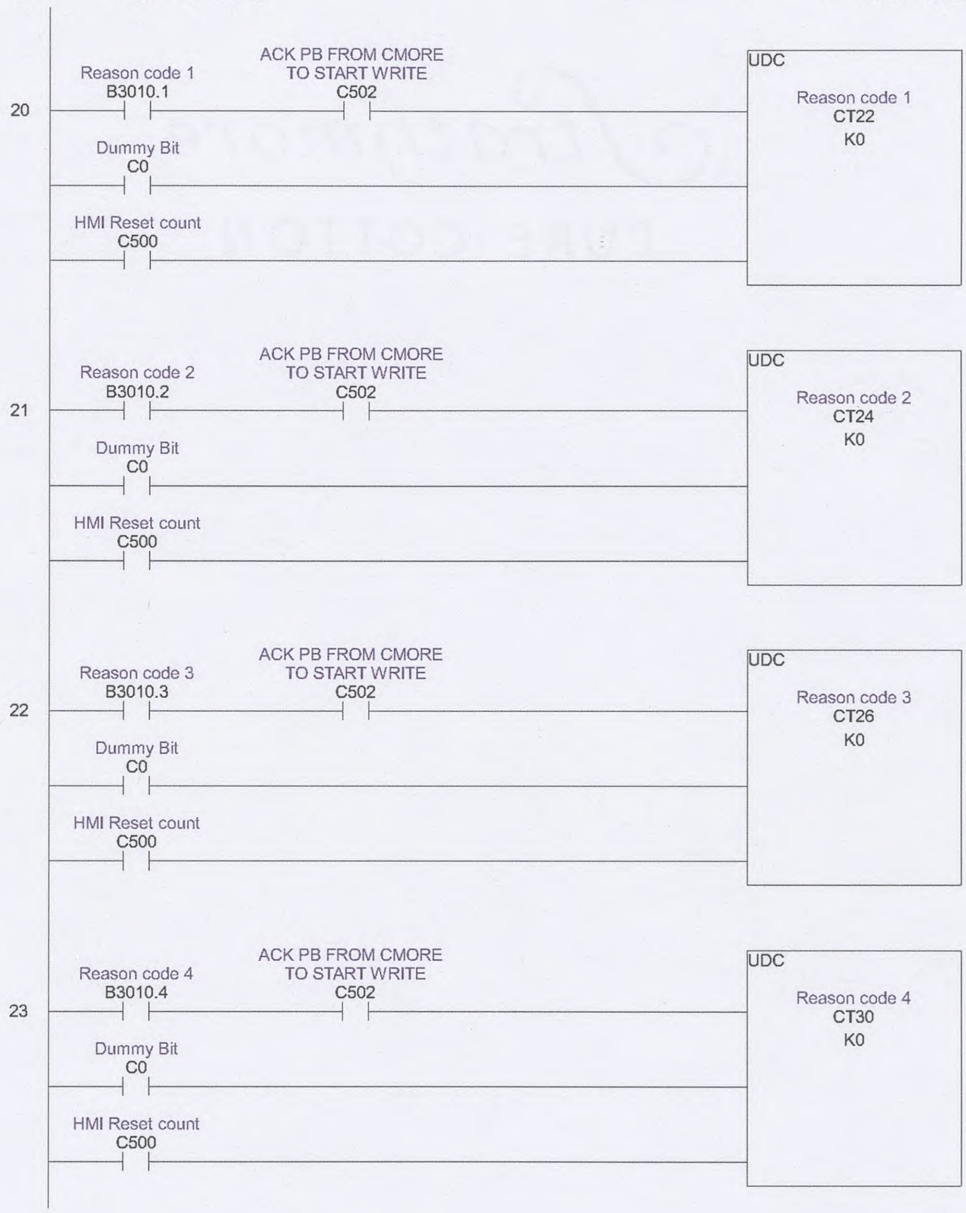
APPENDIX 2

PLC Logic

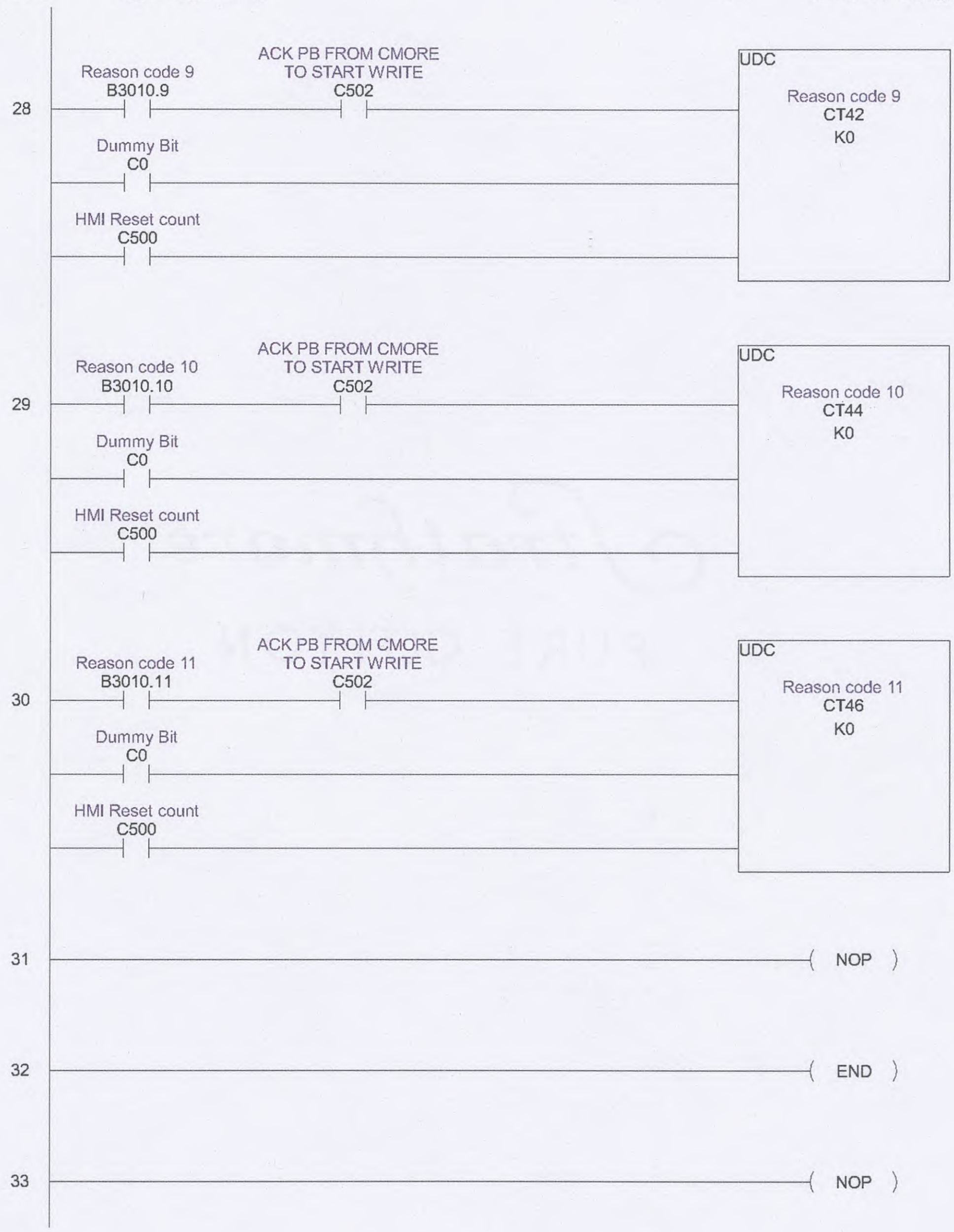

1
HMI System Enable
C1
Machine Cycle
X0
ACK PB FROM CMORE TO START WRITE
C502
TMRA
Machine DownTime Detect
T0
V2000
2
Machine DownTime Detect
T0
HMI Interlock Bypass
C2
Machine Start Interlock
Y4
SET
3
Machine Start Interlock
Y4
HMI Reset count
C500
CNT
DownTime Event Number
CT10
K0
4
Dummy Bit
C0
Math - BCD
MATHBCD IB-521
Result (WORD) V2010
Expression V1010 + K10000
5
NOP
6
HMI Downtime by reason selected OK
C501
Machine Start Interlock
Y4
RST
7
Machine Start Interlock
Y4
HMI System Enable
C1
HMI Reset count
C500
TMRA
Downtime timer
T2
K0


8
Machine Start Interlock
Y4
HMI System Enable
C1
HMI Reset count
C500
TMRA
Uptime Timer
T4
K0
9
NOP
10
Machine Cycle
X0
HMI System Enable
C1
Dummy Bit
C0
HMI Reset count
C500
UDC
Total cycle counter
CT0
K0
11
NOP
12
Good parts
X1
HMI System Enable
C1
Dummy Bit
C0
HMI Reset count
C500
UDC
Good part counter
CT2
K0
13
NOP


14
Bad/Reject Part
X2
HMI System Enable
C1
UDC
Reject part counter
CT4
K0
Dummy Bit
C0
HMI Reset count
C500
15
NOP
16
HMI System Enable
C1
ACK PB FROM CMORE
TO START WRITE
C502
TMR
TIMER TO WRITE DATA
TO LOG
T10
K5
HMI Downtime by
reason selected OK
C501
OUT
17
TIMER TO WRITE DATA
TO LOG
T10
ACK PB FROM CMORE
TO START WRITE
C502
RST
18
NOP
19
Reason code 0
B3010.0
ACK PB FROM CMORE
TO START WRITE
C502
UDC
Reason code 0
CT20
K0
Dummy Bit
C0
HMI Reset count
C500


20
Reason code 1
B3010.1
ACK PB FROM CMORE
TO START WRITE
C502
Dummy Bit
C0
HMI Reset count
C500
UDC
Reason code 1
CT22
K0
21
Reason code 2
B3010.2
ACK PB FROM CMORE
TO START WRITE
C502
Dummy Bit
C0
HMI Reset count
C500
UDC
Reason code 2
CT24
K0
22
Reason code 3
B3010.3
ACK PB FROM CMORE
TO START WRITE
C502
Dummy Bit
C0
HMI Reset count
C500
UDC
Reason code 3
CT26
K0
23
Reason code 4
B3010.4
ACK PB FROM CMORE
TO START WRITE
C502
Dummy Bit
C0
HMI Reset count
C500
UDC
Reason code 4
CT30
K0


24
Reason code 5
B3010.5
ACK PB FROM CMORE
TO START WRITE
C502
Dummy Bit
C0
HMI Reset count
C500
UDC
Reason code 5
CT32
K0
25
Reason code 6
B3010.6
ACK PB FROM CMORE
TO START WRITE
C502
Dummy Bit
C0
HMI Reset count
C500
UDC
Reason code 6
CT34
K0
26
Reason code 7
B3010.7
ACK PB FROM CMORE
TO START WRITE
C502
Dummy Bit
C0
HMI Reset count
C500
UDC
Reason code 7
CT36
K0
27
Reason code 8
B3010.8
ACK PB FROM CMORE
TO START WRITE
C502
Dummy Bit
C0
HMI Reset count
C500
UDC
Reason code 8
CT40
K0


28
Reason code 9
B3010.9
ACK PB FROM CMORE
TO START WRITE
C502
Dummy Bit
C0
HMI Reset count
C500
UDC
Reason code 9
CT42
K0
29
Reason code 10
B3010.10
ACK PB FROM CMORE
TO START WRITE
C502
Dummy Bit
C0
HMI Reset count
C500
UDC
Reason code 10
CT44
K0
30
Reason code 11
B3010.11
ACK PB FROM CMORE
TO START WRITE
C502
Dummy Bit
C0
HMI Reset count
C500
UDC
Reason code 11
CT46
K0
31
NOP
32
END
33
NOP

APPENDIX 3

Touchscreen Screenshots

Tag Database

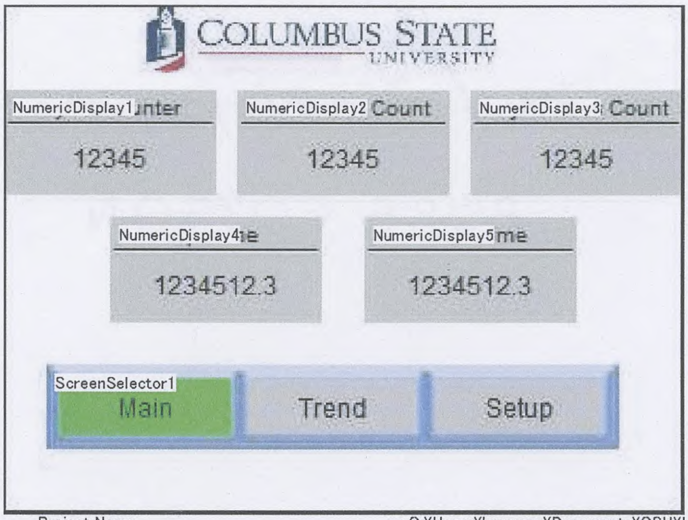
Project Name : C:¥Users¥bromano¥Documents¥CSU¥LeanSixSigma_NEF.eap
No Of Internal Tags : 0
No Of PLC Tags : 13
PLC Protocol : DEV001: AutomationDirect K-Sequence (DL05/06/105/205/350/405)

DEV001

Tag No	Tag Name	Data Type	Data Count	Retentive	Address	Array Start	Array End
1	ACK_DOWNTIME_BIT	Discrete	1	False	C502	0	0
2	CYCLE_COUNTER	BCD int 32	1	False	V1000	0	0
3	DOWNTIME_DETECTED	Discrete	1	False	Y4	0	0
4	DOWNTIME_DURATION	BCD int 32	1	False	V2	0	0
5	DOWNTIME_REASON_CODE	Signed int 16	1	False	V3010	0	0
6	GOOD_PARTS_COUNT	BCD int 32	1	False	V1002	0	0
7	HMI_DOWNTIME_LIMIT	BCD int 32	1	False	V2000	0	0
8	HMI_INTERLOCK_BYPASS	Discrete	1	False	C2	0	0
9	HMI_RESET_DOWNTIME	Discrete	1	False	C500	0	0
10	HMI_SYSTEM_ENABLE	Discrete	1	False	C1	0	0
11	REJECT_COUNTER	BCD int 32	1	False	V1004	0	0
12	UP_TIME_DURATION	BCD int 16	1	False	V4	0	0
13	UP_TIME_DURATION_NEW	BCD int 32	1	False	V4	0	0

StaticBitmap1

1 – Main

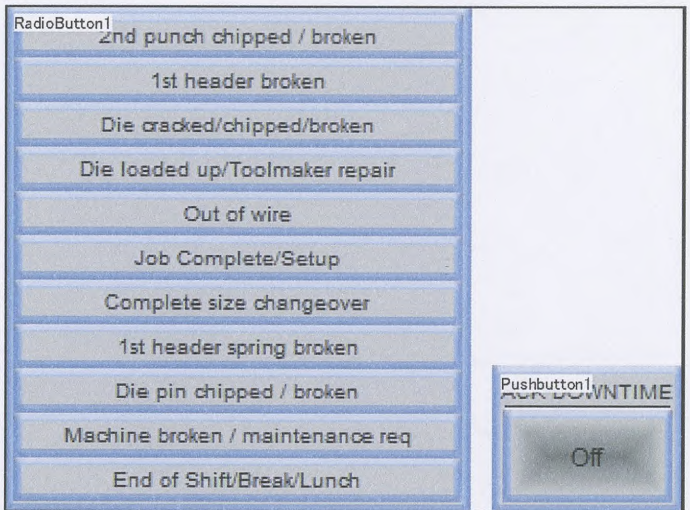


Project Name	: C:¥Users¥bromano¥Documents¥CSU¥LeanSixSigma_NEF.eap
Screen Description	:

[Main]	Name	: StaticBitmap1
	Top-Left/Bottom-Right/Width/Height	: -40,60 70,240 180 110
[General]	Lock Aspect Ratio	: True
	Stretch to Fit	: True
	Transparent/Color	: True/16777215
	Back Color	: 255
	Back Effect	: None
	Angle (in Degree)	: 0

[Main]	Name	: NumericDisplay1
	Display Frame	: False
	Top-Left/Bottom-Right/Width/Height	: 40,0 90,100 100 50
[General]	Label	: True
	Label Text	: 1 – Cycle Counter
		: 2 – NUMERIC DISPLAY
	Label Text Color	: 0
	Label Back Color	: 12
	Label Back Effect	: None
	Label Position/Label Align	: Top/Middle
	Label Text size(Font)	: 8 (Arial)
	Tag Name	: *CYCLE_COUNTER*
	Use Tag For Decimal Point	: False
	Font	: Arial – Default
	Text Size	: 9
	Text Color (Blink)	: 0(False)
	Back Color (Blink)	: 12(False)
	Back Effect	: None
	Data Type	: BCD
	Total Digits/Fractional Digits	: 5/0
	Prefix/Suffix	: /
	Comma Separator	: False
	Justify	: Leading Spaces
[Scaling]	Scaling Option	: False

2 - DownTime by Reason



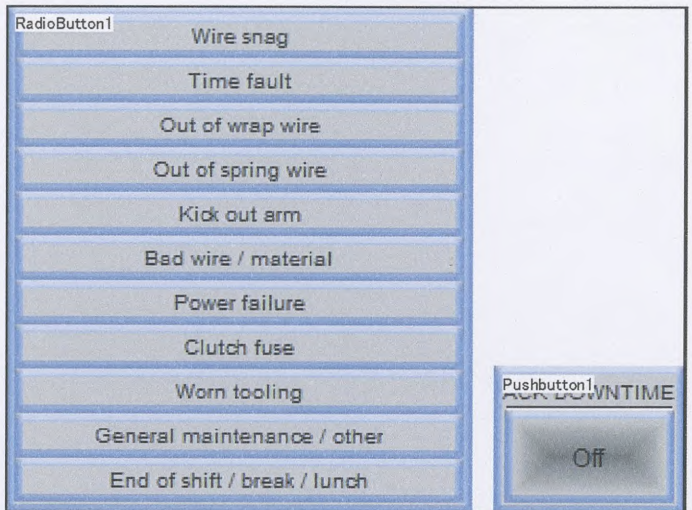
Project Name	: C:¥Users¥bromano¥Documents¥CSU¥LeanSixSigma_NEF.eap
Screen Description	:

[Main]

[General]

Name	: RadioButton1
Display Frame	: True
Top-Left/Bottom-Right/Width/Height	: 0,0 240,220 220 240
Label	: False
Back Color	: 12
Back Effect	: None
Number of Buttons	: 11
Tag Assignment	: Set by Word Tag
Object Style	: Style 2
Tag	: *DOWNTIME_REASON_CODE*
ON Text1	: 1 - 2nd punch chipped / broken : 2 - On #1
ON Text2	: 1 - 1st header broken : 2 - On #2
ON Text3	: 1 - Die cracked/chipped/broken : 2 - On #3
ON Text4	: 1 - up/Toolmaker repair : 2 - On #4
ON Text5	: 1 - Out of wire : 2 - On #5
ON Text6	: 1 - Job Complete/Setup : 2 - On #6
ON Text7	: 1 - Complete size changeover : 2 - On #7
ON Text8	: 1 - 1st header spring broken : 2 - On #8
ON Text9	: 1 - Die pin chipped / broken : 2 - On #9
ON Text10	: 1 - Machine broken / maintenance req : 2 - On #10
ON Text11	: 1 - End of Shift/Break/Lunch : 2 - On #11
ON Text Color Blink	: 0(False)
ON Text Back Color Blink	: 12(True)
ON Text Back Effect	: None
ON Text Font	: Middle (Arial)

2 - DownTime by Reason



Project Name	: C:¥Users¥bromano¥Documents¥CSU¥LeanSixSigma_Uniprise.eap
Screen Description	:

[Main]

[General]

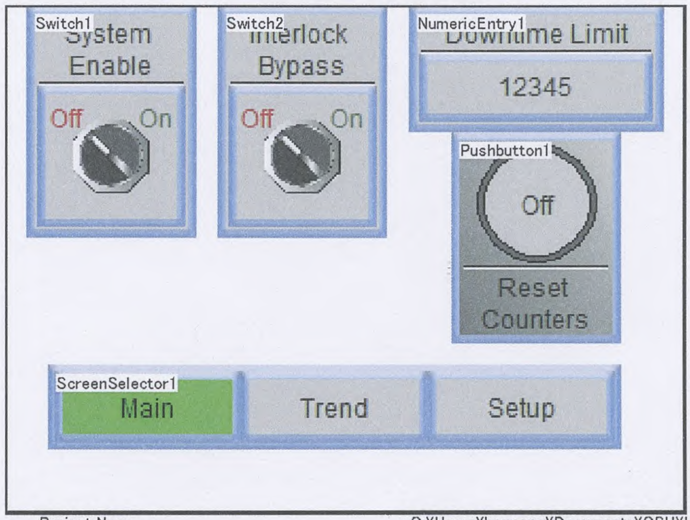
Name	: RadioButton1
Display Frame	: True
Top-Left/Bottom-Right/Width/Height	: 0,0 240,220 220 240
Label	: False
Back Color	: 12
Back Effect	: None
Number of Buttons	: 11
Tag Assignment	: Set by Word Tag
Object Style	: Style 2
Tag	: *DOWNTIME_REASON_CODE*
ON Text1	: 1 - Wire snag : 2 - On #1
ON Text2	: 1 - Time fault : 2 - On #2
ON Text3	: 1 - Out of wrap wire : 2 - On #3
ON Text4	: 1 - Out of spring wire : 2 - On #4
ON Text5	: 1 - Kick out arm : 2 - On #5
ON Text6	: 1 - Bad wire / material : 2 - On #6
ON Text7	: 1 - Power failure : 2 - On #7
ON Text8	: 1 - Clutch fuse : 2 - On #8
ON Text9	: 1 - Worn tooling : 2 - On #9
ON Text10	: 1 - maintenance / other : 2 - On #10
ON Text11	: 1 - End of shift / break / lunch : 2 - On #11
ON Text Color Blink	: 0(False)
ON Text Back Color Blink	: 12(True)
ON Text Back Effect	: None
ON Text Font	: Middle (Arial)

3 – Trend

Project Name	: C:¥Users¥bromano¥Documents¥CSU¥LeanSixSigma_NEF.eap
Screen Description	:

[Main]	Name	: MachineMetrics
	Display Frame	: False
	Top-Left/Bottom-Right/Width/Height	: 0,10 160,310 300 160
[General]	Label	: False
	X-Axis Label	: True
	X-Axis Label Text (Color)	: 1 – Time(50)
		: 2 – X Axis
	X-Axis Division	: True
	X-Axis Major Division/Minor Division	: 4/ 2
	X-Axis Grid	: True
	X-Axis Tick Number	: True
	Y-Axis Label	: True
	Y-Axis Label Text (Color)	: 1 – (50)
		: 2 –
		: 3 –
		: 4 –
		: 5 –
		: 6 –
		: 7 –
		: 8 –
		: 9 –
	Y-Axis Division	: True
	Y-Axis Major Division/Minor Division	: 4/ 2
	Y-Axis Grid	: True
	Y-Axis Tick Number	: True
	Back Color	: 12
	Back Effect	: None
	Axis Tick Marks	: 0
	Object Text size(Font)	: 6x8 (Classic)
	Display Legends	: Normal
	Total Stored Samples	: 100
	Sample per Chart	: 10
	Readings to Average per Sample	: 1
	Data Type	: Unsigned Decimal
	Min / Max	: 0/1000000
	Sample Rate Tag	: Timed Sample Rate

4 - Setup



Project Name	: C:¥Users¥bromano¥Documents¥CSU¥LeanSixSigma_NEF.eap
Screen Description	:

[Main]	Name	: Switch1
	Display Frame	: True
	Top-Left/Bottom-Right/Width/Height	: 0,10 110,90 80 110
[General]	Label	: True
	Label Text	: 1 - System Enable : 2 - SWITCH
	Label Text Color	: 0
	Label Back Color	: 12
	Label Back Effect	: None
	Label Position/Label Align	: Top/Middle
	Label Text size(Font)	: 9 (Arial - Default)
	Tag Name	: *HMI_SYSTEM_ENABLE*
	Object Type	: Toggle
	Back Color	: 12
	Object Style	: Style 1
	Enhanced	: True
	ON Text	: 1 - On
	ON Text Color	: 35(False)
	ON Text Font	: Arial - Default
	ON Text Size	: 9
	OFF Text	: 1 - Off
	OFF Text Color	: 16(False)
	OFF Text Font	: Arial - Default
	OFF Text Size	: 9
[Visibility]	Object Visibility Option	: False
[Option]	Sound Library	: Default (Beep)
	Press Delay	: False
[Password]	Password Option	: False

APPENDIX 4

CASE STUDY 1 CURRENT STATE MODEL AND SIMULATION REPORT

Gooseneck Production Simulation

Replications: 5 Time Units: Hours

Packaging Machine

Description

Nominal Run Speed	
Gooseneck Mfg	900.00

Type	
Gooseneck Mfg	Assembly

Unit Summary

Current Units Inside	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	27008.40	17,678.72	8996.0000	45021.0000

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	-20.00	19.63	-40.0000	0.0000

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	26988.40	17,659.09	8996.0000	44981.0000

Activity Counter

Number of Blockages	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Number of Changeovers	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Number of Failures	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Number of Scheduled Stops	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Performance

Gooseneck Production Simulation

Replications: 5 Time Units: Hours

Packaging Machine

Performance

Average Output Factor	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	1.0000	0.00	1.0000	1.0000

Average Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	900.00	0.00	900.0000	900.0000

Average Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	1.0000	0.00	1.0000	1.0000

Performance Index	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	100.02	0.04	99.9573	100.0462

Yield	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	100.06	0.04	100.0000	100.0889

Total Time

Total Time Blocked	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Changeover	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Failed	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Fast	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	9.9957	0.00	9.9957	9.9957

Total Time Slow	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Values Across All Replications

Gooseneck Production Simulation

Replications: 5 Time Units: Hours

Packaging Machine

Total Time

Total Time Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	10.0000	0.00	10.0000	10.0000

Total Time Starved	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00426867	0.00	0.0043	0.0043

Total Time Stopped	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Working	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	10.0000	0.00	10.0000	10.0000

Usage

Utilization	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	99.96	0.00	99.9573	99.9573

Cost

Total Cost	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Cost of Good Product	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Cost of Lost Product	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Equipment Operating Cost	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

APPENDIX 5

CASE STUDY 1 CURRENT STATE MODEL WITH DATA ACQUIRED FAULTS AND SIMULATION REPORT

Gooseneck Production Simulation

Replications: 5 Time Units: Hours

Packaging Machine

Description

Nominal Run Speed	
Gooseneck Mfg	900.00

Type	
Gooseneck Mfg	Assembly

Unit Summary

Current Units Inside	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	3914.40	2,457.03	1463.0000	6392.0000

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	3914.40	2,457.03	1463.0000	6392.0000

Activity Counter

Number of Blockages	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Number of Changeovers	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Number of Failures	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	518.60	333.29	187.0000	856.0000

Number of Scheduled Stops	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Performance

Gooseneck Production Simulation

Replications: 5 Time Units: Hours

Packaging Machine

Performance

Average Output Factor	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	1.0000	0.00	1.0000	1.0000

Average Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	900.00	0.00	900.0000	900.0000

Average Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	1.0000	0.00	1.0000	1.0000

Performance Index	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	14.7630	1.06	14.2035	16.2605

Yield	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	100.00	0.00	100.0000	100.0000

Total Time

Total Time Blocked	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Changeover	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Failed	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	25.6483	16.90	8.3727	42.8949

Total Time Fast	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	4.3494	2.73	1.6261	7.1018

Total Time Slow	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Gooseneck Production Simulation

Replications: 5 Time Units: Hours

Packaging Machine

Total Time

Total Time Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	4.3517	2.73	1.6273	7.1051

Total Time Starved	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00232707	0.00	0.0013	0.0034

Total Time Stopped	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Working	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	4.3517	2.73	1.6273	7.1051

Usage

Utilization	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	14.7630	1.06	14.2035	16.2605

Cost

Total Cost	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Cost of Good Product	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Cost of Lost Product	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Equipment Operating Cost	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Gooseneck Production Simulation Rerun With Failures From Data Collection Includec

Replications: 5 Time Units: Hours

Key Performance Indicators

System	Average
Number Out	0

Gooseneck Production Simulation Rerun With Failures From Data Collection Includec

Replications: 5 Time Units: Hours

Packaging Machine

Description

Nominal Run Speed	
Gooseneck Mfg	900.00

Type	
Gooseneck Mfg	Assembly

Unit Summary

Current Units Inside	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	3914.40	2,457.03	1463.0000	6392.0000

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	3914.40	2,457.03	1463.0000	6392.0000

Activity Counter

Number of Blockages	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Number of Changeovers	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Number of Failures	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	518.60	333.29	187.0000	856.0000

Number of Scheduled Stops	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Performance

Gooseneck Production Simulation Rerun With Failures From Data Collection Includec

Replications: 5 Time Units: Hours

Packaging Machine

Performance

Average Output Factor	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	1.0000	0.00	1.0000	1.0000

Average Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	900.00	0.00	900.0000	900.0000

Average Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	1.0000	0.00	1.0000	1.0000

Performance Index	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	14.7630	1.06	14.2035	16.2605

Yield	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	100.00	0.00	100.0000	100.0000

Total Time

Total Time Blocked	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Changeover	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Failed	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	25.6483	16.90	8.3727	42.8949

Total Time Fast	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	4.3494	2.73	1.6261	7.1018

Total Time Slow	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Gooseneck Production Simulation Rerun With Failures From Data Collection Included

Replications: 5 Time Units: Hours

Packaging Machine

Total Time

Total Time Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	4.3517	2.73	1.6273	7.1051

Total Time Starved	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00232707	0.00	0.0013	0.0034

Total Time Stopped	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Working	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	4.3517	2.73	1.6273	7.1051

Usage

Utilization	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	14.7630	1.06	14.2035	16.2605

Cost

Total Cost	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Cost of Good Product	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Cost of Lost Product	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Equipment Operating Cost	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

APPENDIX 6

CASE STUDY 1 FUTURE STATE MODEL AND SIMULATION REPORT

Gooseneck Production Simulation Rerun With Failures From Data Collection Includec

Replications: 5 Time Units: Hours

Packaging Machine

Description

Nominal Run Speed	
Gooseneck Mfg	900.00

Type	
Gooseneck Mfg	Assembly

Unit Summary

Current Units Inside	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	4777.40	3,002.25	1736.0000	7780.0000

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	4777.40	3,002.25	1736.0000	7780.0000

Activity Counter

Number of Blockages	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Number of Changeovers	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Number of Failures	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	610.60	389.88	215.0000	1004.0000

Number of Scheduled Stops	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Performance

Gooseneck Production Simulation Rerun With Failures From Data Collection Includec

Replications: 5 Time Units: Hours

Packaging Machine

Performance

Average Output Factor	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	1.0000	0.00	1.0000	1.0000

Average Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	900.00	0.00	900.0000	900.0000

Average Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	1.0000	0.00	1.0000	1.0000

Performance Index	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	17.9637	0.97	17.2885	19.2939

Yield	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	100.00	0.00	100.0000	100.0000

Total Time

Total Time Blocked	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Changeover	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Failed	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	24.6891	16.29	8.0692	41.3518

Total Time Fast	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	5.3082	3.34	1.9294	8.6442

Total Time Slow	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Gooseneck Production Simulation Rerun With Failures From Data Collection Includec

Replications: 5 Time Units: Hours

Packaging Machine

Total Time

Total Time Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	5.3109	3.34	1.9308	8.6482

Total Time Starved	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00268707	0.00	0.0014	0.0040

Total Time Stopped	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Total Time Working	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	5.3109	3.34	1.9308	8.6482

Usage

Utilization	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	17.9637	0.97	17.2885	19.2939

Cost

Total Cost	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Cost of Good Product	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Cost of Lost Product	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

Equipment Operating Cost	Average	Half Width	Minimum Average	Maximum Average
Gooseneck Mfg	0.00	0.00	0.0000	0.0000

APPENDIX 7

CASE STUDY 2 CURRENT STATE MODEL AND SIMULATION REPORT

Cold Header Simulation

Replications: 2 Time Units: Hours

Packaging Machine

Description

Nominal Run Speed	
Cold Formining	6000.00

Type	
Cold Formining	Assembly

Unit Summary

Current Units Inside	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	237998.50	965,649.65	161999.0000	313998.0000

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	237998.50	965,649.65	161999.0000	313998.0000

Activity Counter

Number of Blockages	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Number of Changeovers	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Number of Failures	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	106.00	470.12	69.0000	143.0000

Number of Scheduled Stops	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Performance

Cold Header Simulation

Replications: 2 Time Units: Hours

Packaging Machine

Performance

Average Output Factor	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	1.0000	0.00	1.0000	1.0000

Average Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	6000.00	0.00	6000.0000	6000.0000

Average Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	1.0000	0.00	1.0000	1.0000

Performance Index	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	53.1663	10.59	52.3330	53.9995

Yield	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	100.00	0.00	100.0000	100.0000

Total Time

Total Time Blocked	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Changeover	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Failed	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	35.3333	156.71	23.0000	47.6667

Total Time Fast	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	39.6664	160.94	26.9998	52.3330

Total Time Slow	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Cold Header Simulation

Replications: 2 Time Units: Hours

Packaging Machine

Total Time

Total Time Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	39.6667	160.94	27.0000	52.3333

Total Time Starved	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00027367	0.00	0.0002	0.0003

Total Time Stopped	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Working	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	39.6667	160.94	27.0000	52.3333

Usage

Utilization	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	53.1663	10.59	52.3330	53.9995

Cost

Total Cost	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Cost of Good Product	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Cost of Lost Product	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Equipment Operating Cost	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Unnamed Project

Replications: 5 Time Units: Hours

Packaging Machine

Description

Nominal Run Speed

Cold Formining	6000.00

Type

Cold Formining	Assembly

Unit Summary

Current Units Inside	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	97617.00	66,046.78	29999.0000	164035.0000

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	-20.00	19.63	-40.0000	0.0000

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	97597.00	66,027.17	29999.0000	163995.0000

Activity Counter

Number of Blockages	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Number of Changeovers	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Number of Failures	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	41.2000	25.96	15.0000	68.0000

Number of Scheduled Stops	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Performance

Unnamed Project

Replications: 5 Time Units: Hours

Packaging Machine

Performance

Average Output Factor	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	1.0000	0.00	1.0000	1.0000

Average Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	6000.00	0.00	6000.0000	6000.0000

Average Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	1.0000	0.00	1.0000	1.0000

Performance Index	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	53.5517	2.98	49.9982	55.8440

Yield	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	100.02	0.01	100.0000	100.0244

Total Time

Total Time Blocked	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Changeover	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Failed	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	4.6456	0.30	4.4167	5.0000

Total Time Fast	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	5.3543	0.30	4.9998	5.5832

Total Time Slow	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Unnamed Project

Replications: 5 Time Units: Hours

Packaging Machine

Total Time

Total Time Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	5.3544	0.30	5.0000	5.5833

Total Time Starved	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00018160	0.00	0.0002	0.0002

Total Time Stopped	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Working	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	5.3544	0.30	5.0000	5.5833

Usage

Utilization	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	53.5426	2.97	49.9982	55.8315

Cost

Total Cost	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Cost of Good Product	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Cost of Lost Product	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Equipment Operating Cost	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

APPENDIX 8

CASE STUDY 2 CURRENT STATE MODEL WITH DATA ACQUIRED FAULTS AND SIMULATION REPORT

Cold Header Rerun with Failures From Data Collection Included

Replications: 5 Time Units: Hours

Packaging Machine

Description

Nominal Run Speed

Cold Forming	6000.00

Type

Cold Forming	Assembly

Unit Summary

Current Units Inside	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	0.00	0.00	0.0000	0.0000

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	84823.40	60,021.79	22573.0000	143669.0000

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	23.8000	15.76	9.0000	40.0000

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	84847.00	60,037.34	22582.0000	143708.0000

Activity Counter

Number of Blockages	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	0.00	0.00	0.0000	0.0000

Number of Changeovers	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	0.00	0.00	0.0000	0.0000

Number of Failures	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	14.8000	9.47	6.0000	25.0000

Number of Scheduled Stops	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	0.00	0.00	0.0000	0.0000

Performance

Cold Header Rerun with Failures From Data Collection Included

Replications: 5 Time Units: Hours

Packaging Machine

Performance

Average Output Factor	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	1.0000	0.00	1.0000	1.0000

Average Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	6000.00	0.00	6000.0000	6000.0000

Average Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	1.0000	0.00	1.0000	1.0000

Performance Index	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	45.4708	5.98	37.6222	49.3300

Yield	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	99.97	0.01	99.9601	99.9736

Total Time

Total Time Blocked	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Changeover	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Failed	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	15.8586	9.65	6.2361	26.0484

Total Time Fast	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	14.1412	10.01	3.7637	23.9514

Total Time Slow	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Cold Header Rerun with Failures From Data Collection Included

Replications: 5 Time Units: Hours

Packaging Machine

Total Time

Total Time Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	14.1414	10.01	3.7639	23.9516

Total Time Starved	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00018167	0.00	0.0002	0.0002

Total Time Stopped	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Working	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	14.1414	10.01	3.7639	23.9516

Usage

Utilization	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	45.4841	5.97	37.6372	49.3433

Cost

Total Cost	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Cost of Good Product	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Cost of Lost Product	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Equipment Operating Cost	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Unnamed Project

Replications: 5 Time Units: Hours

Packaging Machine

Description

Nominal Run Speed

Cold Forming	6000.00

Type

Cold Forming	Assembly

Unit Summary

Current Units Inside	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	0.00	0.00	0.0000	0.0000

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	84823.40	60,021.79	22573.0000	143669.0000

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	23.8000	15.76	9.0000	40.0000

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	84847.00	60,037.34	22582.0000	143708.0000

Activity Counter

Number of Blockages	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	0.00	0.00	0.0000	0.0000

Number of Changeovers	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	0.00	0.00	0.0000	0.0000

Number of Failures	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	14.8000	9.47	6.0000	25.0000

Number of Scheduled Stops	Average	Half Width	Minimum Average	Maximum Average
Cold Forming	0.00	0.00	0.0000	0.0000

Performance

Unnamed Project

Replications: 5 Time Units: Hours

Packaging Machine

Performance

Average Output Factor	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	1.0000	0.00	1.0000	1.0000

Average Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	6000.00	0.00	6000.0000	6000.0000

Average Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	1.0000	0.00	1.0000	1.0000

Performance Index	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	45.4708	5.98	37.6222	49.3300

Yield	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	99.97	0.01	99.9601	99.9736

Total Time

Total Time Blocked	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Changeover	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Failed	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	15.8586	9.65	6.2361	26.0484

Total Time Fast	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	14.1412	10.01	3.7637	23.9514

Total Time Slow	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Unnamed Project

Replications: 5 Time Units: Hours

Packaging Machine

Total Time

Total Time Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	14.1414	10.01	3.7639	23.9516

Total Time Starved	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00018167	0.00	0.0002	0.0002

Total Time Stopped	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Working	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	14.1414	10.01	3.7639	23.9516

Usage

Utilization	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	45.4841	5.97	37.6372	49.3433

Cost

Total Cost	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Cost of Good Product	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Cost of Lost Product	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Equipment Operating Cost	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

APPENDIX 9

CASE STUDY 2 FUTURE STATE MODEL AND SIMULATION REPORT

Cold Header Rerun with Failures From Data Collection Included

Replications: 5 Time Units: Hours

Packaging Machine

Description

Nominal Run Speed

Cold Formining	6000.00

Type

Cold Formining	Assembly

Unit Summary

Current Units Inside	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	99426.00	65,806.53	30446.0000	164398.0000

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	19.2000	10.87	7.0000	30.0000

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	99445.00	65,817.54	30453.0000	164428.0000

Activity Counter

Number of Blockages	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Number of Changeovers	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Number of Failures	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	12.8000	8.25	4.0000	21.0000

Number of Scheduled Stops	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Performance

Cold Header Rerun with Failures From Data Collection Included

Replications: 5 Time Units: Hours

Packaging Machine

Performance

Average Output Factor	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	1.0000	0.00	1.0000	1.0000

Average Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	6000.00	0.00	6000.0000	6000.0000

Average Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	1.0000	0.00	1.0000	1.0000

Performance Index	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	54.6735	2.93	50.7433	57.0609

Yield	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	99.98	0.00	99.9770	99.9820

Total Time

Total Time Blocked	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Changeover	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Failed	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	13.4257	8.68	4.9243	22.5951

Total Time Fast	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Output Rate Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	16.5742	10.97	5.0755	27.4047

Total Time Slow	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Cold Header Rerun with Failures From Data Collection Included

Replications: 5 Time Units: Hours

Packaging Machine

Total Time

Total Time Speed Factor Greater Than 0	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	16.5743	10.97	5.0757	27.4049

Total Time Starved	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00018007	0.00	0.0002	0.0002

Total Time Stopped	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Total Time Working	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	16.5743	10.97	5.0757	27.4049

Usage

Utilization	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	54.6846	2.93	50.7550	57.0720

Cost

Total Cost	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Cost of Good Product	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Cost of Lost Product	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

Equipment Operating Cost	Average	Half Width	Minimum Average	Maximum Average
Cold Formining	0.00	0.00	0.0000	0.0000

LIST OF POCKET MATERIALS

Items listed below are contained on the enclosed digital media storage

Number

1. Case Study 1 Current State Arena Model file
2. Case Study 1 Current State Arena Report File
3. Case Study 1 Current State with Data Acquired Faults Arena File
4. Case Study 1 Current State with Data Acquired Faults Arena Report Data File
5. Case Study 1 Current State with Data Acquired Faults and Recommended Improvements Arena File
6. Case Study 1 Current State with Data Acquired Faults Arena and Recommended Improvements Report Data File
7. Case Study 1 Data Acquisition and Analysis Excel File
8. Case Study 2 Current State Arena Model File
9. Case Study 2 Current State Arena Report File
10. Case Study 2 Current State with Data Acquired Faults Arena File
11. Case Study 2 Current State with Data Acquired Faults Arena Report Data File
12. Case Study 2 Current State with Data Acquired Faults and Recommended Improvements Arena File
13. Case Study 2 Current State with Data Acquired Faults Arena and Recommended Improvements Report Data File
14. Case Study 2 Data Acquisition and Analysis Excel File